Chapter 5
Academic Research and Development

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Highlights

Financial Resources for Academic R&D

In 2006, U.S. academic institutions spent $48 billion on R&D. Since 2000, average annual growth in R&D was stronger for the academic sector than for any other R&D-performing sector.

- ♦ Academic R&D reached about 0.4% of the gross domestic product in 2006.
- ♦ Academic performers are estimated to account for 56% of U.S. basic research ($61 billion), about 33% of total (basic plus applied) research ($140 billion), and 14% of all R&D ($340 billion) estimated to have been conducted in the United States in 2006.

All reported sources of support for academic R&D (federal, industrial, state and local, and institutional) increased fairly continuously in absolute dollar terms between 1972 and 2000, even after adjusting for inflation. Beginning in 2001, funding from industry declined for 3 straight years but then rebounded between 2004 and 2006. Support from the federal government decreased in 2006 as funding growth failed to outpace inflation for the first time since 1982.

- ♦ The federal government provided 63% of funding for academic R&D expenditures in 2006, representing substantial growth from the 58% share of support provided in 2000 but less than the 68% share supplied in 1972.
- ♦ Institutions themselves contributed 19% of funds in 2006, compared with 12% in 1972.
- ♦ Industry's share of academic R&D support grew rapidly during the 1970s and 1980s, fluctuated around 7% of the total during the 1990s, and declined thereafter to 5% in 2003 as a result of absolute constant dollar declines in 2002 and 2003. Despite the recent increase in absolute dollars between 2004 and 2006, industry's share remained at 5% in 2006.

Between 1996 and 2006, the distribution of academic R&D funds received by different S&E fields remained relatively constant, with the largest shift in the field of life sciences.

- ♦ Only the life sciences and psychology (up 5.2 and 0.2 percentage points, respectively) saw their share of the academic R&D total increase between 1996 and 2006.
- ♦ The share held by engineering decreased by 1.3 percentage points between 1996 and 2006 after having gained almost 5 percentage points overall between 1975 and 1996.
- ♦ The fields of environmental sciences, mathematics, physical sciences, and social sciences experienced modest share declines between 1996 and 2006 (1.0, 0.1, 1.8, and 1.2 percentage points, respectively).
- ♦ The social sciences experienced the largest decrease in share over the past three decades, dropping by more than half from 7.5% in 1975 to 3.6% in 2006.

The share of all academic R&D funded by the federal government varies significantly by field, and the fields of life sciences and psychology have seen the largest increases in their federal share in recent years.

- ♦ The fields with the largest share of federally funded R&D in 2006 were the atmospheric sciences (80%), physics (75%), aeronautical/astronautical engineering (74%), and psychology (72%).
- ♦ Economics (35%), political science (34%), and the agricultural sciences (32%) had the smallest shares of federal funding in 2006.
- ♦ Between 1998 and 2004, the period in which federal policies doubled the R&D budget of the National Institutes of Health, the share of federally financed R&D funding for the life sciences increased rapidly, from 57% to 64%, and the share in psychology increased from 67% to 75%.

The historical concentration of academic R&D funds among the top research universities has remained relatively steady over the past 20 years.

- ♦ In terms of total R&D funding, the share of all academic R&D expenditures received by the top 100 academic institutions decreased from 83% to 80% between 1986 and 1993 and has remained at that level through 2006.
- ♦ Only 5 of the top 20 institutions in 1986 were not in the top 20 in 2006.

In 2006, although about $1.8 billion in current funds was spent on R&D equipment, the share of all annual R&D expenditures spent on research equipment continued a two-decade decline.

- ♦ After reaching a high of 7% in 1985 and 1986, the share of R&D spent on equipment declined to 4% in 2006.
- ♦ About 83% of equipment expenditures were concentrated in the life sciences (41%), engineering (24%), and the physical sciences (18%).
- ♦ After more than doubling in constant 2000 dollars between 1985 and 2004, the life sciences subfields of medical and biological sciences experienced declines in equipment expenditures in 2005 and 2006. Engineering equipment expenditures also doubled between 1985 and 2005 but declined in 2006.

Research-performing colleges and universities continued to expand their stock of research space in FY 2005, but at a significantly slower rate than in the previous 2-year period. In addition to the traditional "bricks and mortar" research infrastructure, "cyberinfrastructure" may be playing an increasingly important role in the conduct of S&E research.

♦ In FY 2004–05, all S&E fields except for the earth, atmospheric, and ocean sciences experienced increases in research space.

♦ Based on current construction of new space and plans for new construction, the biological and medical sciences will continue to dominate the share of total research space and funds for new construction.

♦ In FY 2005, 21% of academic institutions reported bandwidth of 1 gigabit or faster, and this percentage is estimated to increase to 30% in FY 2006.

Doctoral Scientists and Engineers in Academia

The size of the doctoral academic S&E workforce reached an estimated 274,200 in 2006 but grew more slowly than the number of S&E doctorate holders in other employment sectors. Full-time tenure-track faculty positions, although still the predominant employment mode, increased more slowly than postdoc and other full- and part-time positions, especially at research universities.

♦ The academic share of all doctoral S&E employment dropped from 55% in 1973 to 45% in 2006.

♦ The share of full-time faculty declined from 88% in the early 1970s to 72% in 2006. Other full-time positions rose to 14% of the total, and postdoc and part-time appointments stood at 9% and 6%, respectively.

The demographic composition of the academic doctoral labor force changed substantially between 1973 and 2006.

♦ The number of women in academia increased more than eightfold, from 10,700 to about 90,700, raising their share from 9% to 33%.

♦ The number of underrepresented minorities (blacks, Hispanics, and American Indians/Alaska Natives) rose about ninefold, from 2,400 to 22,400, but remain a small percentage (8%) of the S&E doctorate holders in academia.

♦ The number of Asians/Pacific Islanders entering the academic S&E doctoral workforce, many of them foreign born, increased substantially, from 5,000 to about 38,800, raising their share from 4% to 14%.

♦ The share of whites in the academic S&E doctoral workforce fell during the period from 91% to 78%; the white male share fell from about 83% to about 52%.

Foreign-born scientists and engineers are an increasing share of doctoral S&E faculty.

♦ Foreign-born scientists and engineers were 28% of all full-time doctoral S&E faculty in 2003, up from 21% in 1992.

♦ In the physical sciences, mathematics, computer sciences, and engineering, 47% of full-time doctoral S&E faculty in research institutions were foreign born, up from 38% in 1992.

The average age of the academic doctoral labor force has been rising during the past quarter century.

♦ Both the mean age (42–48) and median age (40–48) increased almost monotonically between 1973 and 2006.

♦ In 2006, a growing, albeit small, fraction of employment (6%) was made up of individuals age 65 or older.

♦ Retirement rates remained relatively stable from 1993 to 2003.

A substantial academic researcher pool has developed outside the regular faculty ranks.

♦ Postdocs and others in full-time nonfaculty positions constitute an increasing percentage of those doing research at academic institutions, having grown from 13% in 1973 to 27% in 2006. This change was especially pronounced in the 1990s.

♦ The share of full-time doctoral S&E instructional faculty who are engaged primarily in research increased from 20% to 26% between 1992 and 2003.

In most fields, the percentage of academic researchers with federal support for their work was about the same in 2006 as it was in the late 1980s.

♦ Among all academic S&E doctorate holders employed in academia, 47% received federal support in 2006, compared with 48% in 1989.

♦ Among life scientists, the percentage of academic S&E doctorate holders with federal support dropped from 65% in 1989 to 58% in 2006, although the actual number reporting federal support increased during the period.

♦ Full-time doctoral S&E faculty in the academic workforce were less likely to receive federal support (46%) than postdocs (71%).

♦ Among full-time faculty, recent doctorate recipients were less likely to receive federal support than their more established colleagues.

Outputs of S&E Research: Articles and Patents

S&E article output worldwide grew at an average annual rate of 2.3% between 1995 and 2005, but the U.S. growth rate was much lower.

♦ U.S. output grew 0.6% annually over the same period, compared with 1.8% for the European Union and 6.6% for a group of 10 Asian countries/economies (Asia-10), including China at 17% and South Korea at 16%.

♦ The U.S. share of total world article output fell between 1995 and 2005, from 34% to 29%, as did the European Union share, which declined from 35% to 33%, whereas the Asia-10 share increased from 13% to 20%.

On a national basis, the United States, Japan, the United Kingdom, and Germany dominated total S&E article output in both 1995 and 2005.

- China advanced from 14th to 5th place overall, to 2nd place in engineering and chemistry, and to 3rd place in physics and mathematics.
- South Korea, Brazil, and Turkey, not among the top 20 national producers in 1995, held 10th, 17th, and 19th place, respectively, in 2005.

S&E research is an increasingly collaborative activity. Between 1988 and 2005, the share of publications with authors from multiple institutions grew from 40% to 61%.

- Coauthored articles with only domestic institutions in the bylines grew from 32% to 41% of all articles.
- Articles with institutions from multiple countries—an indicator of international collaboration and the globalization of science—grew from 8% to 20%.

The United States has the largest share of all internationally authored articles, and U.S. researchers collaborate most often with counterparts in Germany, the United Kingdom, and Canada.

- However, when U.S. international collaboration is normalized for the volume of its partner's international coauthorship, only collaboration between the United States and Canada, Israel, South Korea, and Taiwan is more frequent than would be predicted.
- Higher rates of research collaboration are to be found, for example, between Argentina and Brazil, South Korea and Japan, Australia and New Zealand, and among the Scandinavian countries.

Indicators of collaboration based on coauthorship among U.S. sectors and between U.S. sectors and foreign authors show that integration of R&D activities is occurring across the full range of R&D-performing institutions in the United States.

- U.S. cross-sectoral coauthorship between all sectors except federally funded research and development centers (FFRDCs) and industry increased during the 1995–2005 period. The largest gains in all sectors were with coauthors in academia: By 2005, the percentage of articles with coauthors from academia was 71% for state/local government, 62% for private nonprofit institutions, and 59% for the federal government.
- Between 1995 and 2005, coauthorship with foreign authors increased by 10 percentage points for authors in FFRDCs, industry, and private nonprofit institutions and by 9 percentage points for authors in the federal government and academia.
- Of the S&E fields, astronomy had the highest rate of international coauthorship in 2005, at 58%, well above the U.S. national average of 27% across all fields.

Although the U.S. share of world article output and article citations has declined, the influence of U.S. research articles has increased, as indicated by the percentage of U.S. articles that are among the most highly cited worldwide.

- In 1995, authors from U.S. institutions had 73% more articles in the top 1% of cited articles in all S&E fields than would be expected based on U.S. total article output; in 2005, the percentage had grown to 83%.
- In 2005, the European Union had 16% fewer articles in the top 1% of cited articles than would be expected, and the Asia-10 had 59% fewer than would be expected. However, both the European Union and Asia-10 have advanced on this indicator since 1995.

Indicators of academic patenting are mixed. The U.S. Patent and Trademark Office (USPTO) reports that patent grants to universities have declined since 2002, but other indicators suggest continued expansion of activities related to patents and patent/licensing revenues.

- According to USPTO, patent grants to universities and colleges increased sharply from 1995 to about 2002, when they peaked at just under 3,300 patents per year, and then fell to about 2,700 in 2005. Three biomedically related patent classes continued to dominate these awards, accounting for more than one-third in 2005.
- Other data indicate, however, that invention disclosures filed with university technology management offices grew from 13,700 in 2003 to 15,400 in 2005 and that patent applications filed by reporting universities and colleges increased from 7,200 in 2003 to 9,500 in 2004 and 9,300 in 2005.
- University inventories of revenue-generating licenses and options also continued to grow, as did the annual number of new licenses and options executed. The annual number of startup companies established as a result of university-based inventions rebounded after 2 years of downturns in 2002 and 2003 to more than 400 in both 2004 and 2005.

Introduction

Chapter Overview

U.S. universities and colleges are key contributors to the nation's S&E enterprise. The academic sector develops scientists and engineers through its education and training activities (see chapter 2, "Higher Education in Science and Engineering") and generates new knowledge and ideas through its research activities. Almost 60% of the nation's basic research and about a third of its total research are carried out in academic institutions. The federal government has been and continues to be the major financial supporter of academic R&D, providing almost two-thirds of the funding in 2005. Other major funding sources are the institutions themselves, industry, and state and local government.

The allocation of the national academic R&D investment has been changing over time, with the share going to the life sciences growing substantially over the past several decades. This has prompted serious discussion about the appropriate distribution of funds across disciplines. The President's FY 2008 R&D budget signals a goal to double federal funds for agencies supporting physical sciences and engineering research over the coming decade.

Doctoral S&E faculty in universities and colleges play a critical role in performing research and in ensuring a well-trained, diverse supply of S&E personnel for all sectors of the economy. Hiring of S&E doctorate holders into academic positions over the past decade suggests a relative decline in reliance on full-time tenure-track faculty positions in favor of other forms of employment. This shift is expected to continue as academia approaches a period of potentially increasing retirements because of its aging labor force. The demographic composition of new hires is likely to continue the trend toward more women and minorities that mirrors similar changes in the student population. Trends in foreign-born faculty and foreign graduate students, stabilizing after the events of September 11, 2001, remain uncertain because of the rapid development of higher education and research capacities in many countries and the growing international competition for highly skilled talent. All these changes will affect the composition and teaching and research roles of the future doctoral S&E faculty.

A measure of research output, the number of U.S. S&E articles published in the world's leading S&E journals, recently began to increase after remaining flat for almost a decade. During that time, the number of articles by scientists in the European Union (EU) and several Asian countries grew strongly. As a result of these combined trends, the U.S. share of the world's S&E article output has declined since the early 1970s. The number of influential articles from U.S. institutions, as measured by citation frequency, remained fairly flat, and as a result, the U.S. share of the world's influential articles also declined. However, U.S. scientific publications remain influential relative to those of other countries.

Article output by the academic sector, which publishes most U.S. research articles, mirrored the overall U.S. trend, even though research inputs (specifically, academic R&D expenditures and research personnel) continued to increase. Both domestic and international collaboration have increased significantly over the past two decades as academic scientists and engineers collaborated extensively with colleagues in other U.S. sectors (federal and state government, industry, nonprofit institutions, and federally funded research and development centers) and abroad. The results of academic S&E research increasingly extend beyond articles to patents, which are an indicator of academic institutions' efforts to protect the intellectual property derived from their inventions, technology transfer, and university-industry collaboration, and other related activities such as revenue-generating licenses and formation of startup companies.

To help provide a context for discussions about the organization, focus, and mission of U.S. universities and colleges, this chapter addresses key aspects of the academic R&D enterprise, including the level, field allocation, and institutional distribution of academic R&D funds; the state of research equipment and facilities at academic institutions; trends in the number and composition of the academic S&E doctoral labor force; and indicators of research outputs.

Chapter Organization

The first section of this chapter discusses the role of academia within the national R&D enterprise. This discussion is followed by an examination of trends in the financial resources provided for academic R&D, including identification of key funders and allocations of funds 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 to both overall support and support for individual fields is explored in some detail. This section also presents data on changes in the distribution of funds among academic institutions and on the number of academic institutions that receive federal R&D support. It concludes with an examination of the status of two key elements of university research activities: equipment and infrastructure, including cyberinfrastructure.

The next section discusses trends in employment of academic doctoral scientists and engineers with special reference to research. Major trends examined include numbers of academic doctoral scientists and engineers, the types of institutions in which they are employed, the types of positions they hold, their research activities, and federal support for research. Differences between S&E faculty and non-S&E faculty and between doctoral and nondoctoral S&E faculty are taken into account. The section also examines shifts in faculty age structure, trends in retirement patterns, and demographic characteristics, including characteristics and employment patterns of recent doctorate holders entering academic positions and participation of women and minorities.

The chapter concludes with an analysis of trends in two types of research outputs: S&E articles, as 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 this chapter and chapter 2.) This section looks specifically at the volume of research (article counts), collaboration in the conduct of research (joint authorship), and use in subsequent scientific activity (citation patterns). 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.[1] To carry out world-class research and advance the scientific knowledge base, U.S. academic researchers require financial resources, stability of research support, 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 shares
- 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 across institutions that perform 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 equipment and facilities)

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 as follows:

- Growth in federal funding of academic R&D has slowed.
- Continued but differential increases in funding for all fields resulted in a relative shift in the distribution of funds, with increasing shares for the life sciences, engineering, and the computer sciences.
- The field of medical sciences experienced the largest increase in the past several decades, its share having risen by 10 percentage points since 1975.
- R&D activity expanded to a wider set of institutions, but the concentration of funds among the top research universities remained relatively constant over the past two decades.
- The share of all annual R&D expenditures spent on research equipment reached a historic low.
- Growth in academic S&E research space continued, particularly in the medical and biological sciences.

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

Academic R&D Within the National R&D Enterprise

Academia plays an important role in the nation’s overall R&D effort, especially by contributing 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 2006, U.S. academic institutions spent $48 billion, or $41 billion in constant 2000 dollars, on R&D.[2] Academia’s role as an R&D performer increased during the past three decades, rising from about 10% of all R&D performed in the United States in the early 1970s to an estimated 14% in 2006 (figure 5-1). For a comparison with other countries, see “International R&D Comparisons” in chapter 4.

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.[3] For the definitions used in National Science Foundation (NSF) surveys and a fuller discussion of these concepts, see chapter 4 sidebar, “Definitions of R&D.” In 2006, an estimated 96% of academic R&D expenditures went for research (75% for basic and 22% for applied) and 4% for development (figure 5-2; appendix table 5-1). From the perspective of national research (basic and applied), as opposed to national R&D, academic institutions accounted for an estimated 33% of the U.S. total in 2006. In terms of basic research alone, the academic sector is the country’s largest performer, currently accounting for an estimated 56% of the national total. Between the early 1970s and early 1980s, the academic sector’s basic research share declined from slightly more to slightly less than one-half of the national total (figure 5-1). In the early 1990s, its share of the national total began to increase once again.

Growth

Between 1970 and 2006, the average annual R&D growth rate (in constant 2000 dollars) of the academic sector (4.3%) was higher than that of any other R&D-performing sector except the nonprofit one (4.6%). (See figure 5-3 and appendix table 4-4 for time-series data by R&D-performing sector.) Since 2000, the academic sector has grown faster than any U.S. R&D-performing sector (4.6%). As a proportion of gross domestic product (GDP), academic R&D rose from 0.24% in 1970 to 0.35% in 2006, almost a 50% increase. (See appendix table 4-1 for GDP time series.)

Data Sources for Financial Resources for Academic R&D

The data used to describe financial and infrastructure resources for academic R&D are derived from four National Science Foundation (NSF) surveys. These surveys use similar but not always identical definitions, and the nature of the respondents also differs across the surveys. The four main surveys are as follows:

- 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 Science and Engineering Research Facilities

The first two surveys collect data from federal agencies, whereas the last two collect data from universities and colleges. (For descriptions of the methodologies of the NSF surveys, see NSF/SRS 1995a, b and the Division of Science Resources Statistics website, http://www.nsf.gov/statistics/.)

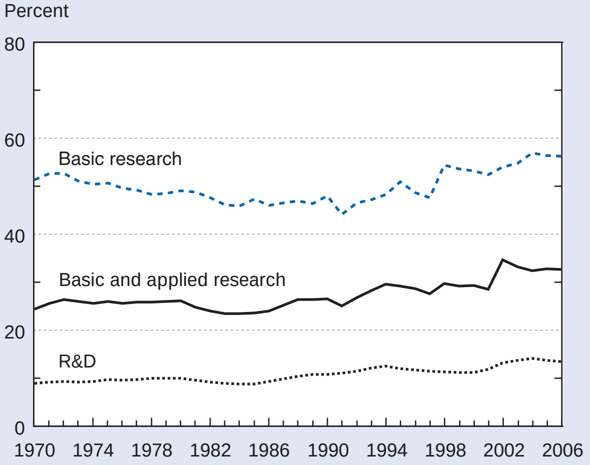
Data presented in the context section, "Academic R&D Within the National R&D Enterprise," are derived from special tabulations that aggregate NSF survey data on the various sectors of the U.S. economy so that the components of the overall R&D effort are placed in a national context. These data are reported on a calendar-year basis, and the data for 2005 and 2006 are preliminary. Since 1998, these data also attempt to eliminate double counting in the academic sector by subtracting current fund expenditures for separately budgeted S&E R&D that do not remain in the institution reporting them but are passed through to other institutions via subcontracts and similar collaborative research arrangements. Data in subsequent sections are reported on a fiscal-year basis and do not net out the funds passed through to other institutions, and therefore differ from those reported in this section. 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 "Federal Support of Academic R&D" section come primarily from NSF's Survey of Federal Funds for Research and Development. This survey collects data on R&D obligations from 30 federal agencies. Data for FY 2006 and FY 2007 are preliminary estimates. The amounts reported for FY 2006 and FY 2007 are based on administration budget proposals and do not necessarily represent actual appropriations. Data on federal obligations by S&E field are available only through FY 2005. They 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 research equipment are taken from the Survey of Research and Development Expenditures at Universities and Colleges. Data on research facilities and cyberinfrastructure are taken from the Survey of Science and Engineering Research Facilities. These two surveys do not cover the same populations. The minimum threshold for inclusion in the expenditures survey is $150,000 in expenditures, whereas the minimum threshold for inclusion in the facilities survey is $1 million. The facilities survey was redesigned for FY 2003 implementation and its topics broadened to include computing and networking capacity as well as research facilities. Data reported on various characteristics of research space are imputed for item nonresponse and weighted to national estimates for unit nonresponse. The data reported on networking and information technology planning are not imputed or weighted. Although terms are defined specifically in each survey, in general, *facilities expenditures* are classified as *capital* funds, are fixed items such as buildings, 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 in this chapter) are purchased with *current funds* (those in the yearly operating budget for ongoing activities) and included within R&D expenditures. Because donated research equipment is not typically captured in university accounting systems, the value of donated research equipment is not reported. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment. Generally, academic institutions keep separate accounts for current and capital funds.

Figure 5-1
Academic R&D, basic and applied research, and basic research as share of total of each category: 1970–2006



NOTES: Preliminary data for 2005 and 2006. Because of changes in estimation procedures, character of work data before FY 1998 not comparable with later years. Data based on annual reports by performers. For details on methodological issues of measurement, see National Science Foundation, Division of Science Resources Statistics (NSF/SRS), National Patterns of R&D Resources: Methodology Report (forthcoming).

SOURCE: NSF/SRS, National Patterns of R&D Resources (annual series). See appendix table 5-1. Also see appendix tables 4-3, 4-7, 4-11, and 4-15 for data underlying percentages.

Science and Engineering Indicators 2008

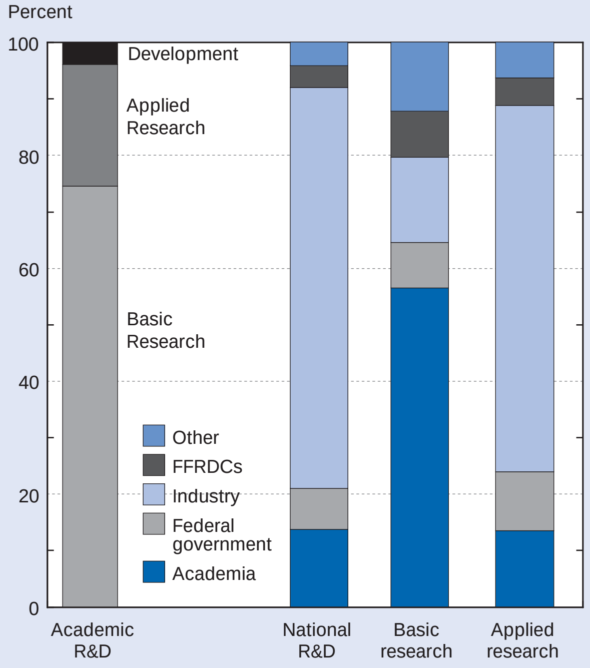
Major Funding Sources

The academic sector relies on a variety of funding sources for support of its R&D activities, although the federal government has consistently contributed the majority of the funds (figure 5-4). In 2006, the federal government accounted for about 63% of the funding of the $48 billion of R&D performed in academic institutions (figure 5-5; appendix table 5-2). This share represents a slight decline after an increase from 58% to 64% between 2000 and 2004. In 2006, federal funding failed to outpace inflation for the first time since 1982.

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:[4]

- **Institutional funds.** In 2006, institutional funds from universities and colleges constituted the second largest source of funding for academic R&D, accounting for 19% ($9.1 billion), slightly below a peak of 20% in 2001 (appendix table 5-2). Institutional funds encompass two categories: (1) institutionally financed organized research expenditures and (2) unreimbursed indirect costs and related sponsored research. They do not include departmental research and thus exclude funds (notably for faculty salaries) in cases in which research activities are not separately budgeted.

Figure 5-2
Academic R&D expenditures, by character of work, and national R&D expenditures, by performer and character of work: 2006



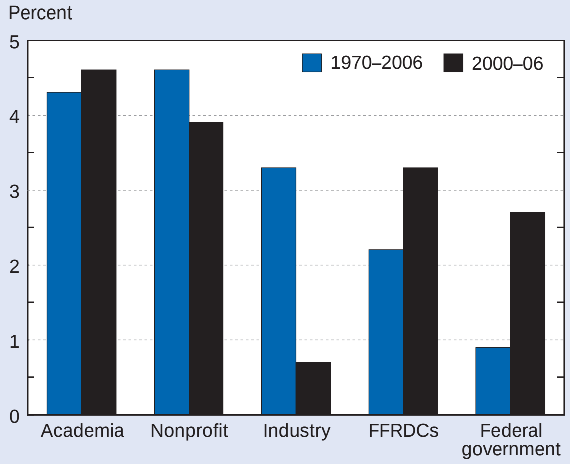
FFRDC = federally funded research and development center

NOTE: Preliminary data.

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 and Engineering Indicators 2008

Figure 5-3
Average annual R&D growth, by performing sector: 1970–2006 and 2000–06



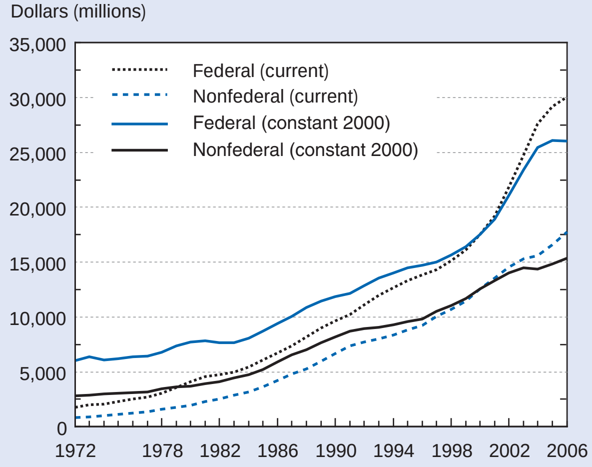
FFRDC = federally funded research and development center

NOTE: R&D data for calendar year.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources, special tabulations (preliminary data for 2005 and 2006). See appendix table 4-4.

Science and Engineering Indicators 2008

Figure 5-4
Federal and nonfederal academic R&D expenditures: 1973–2006

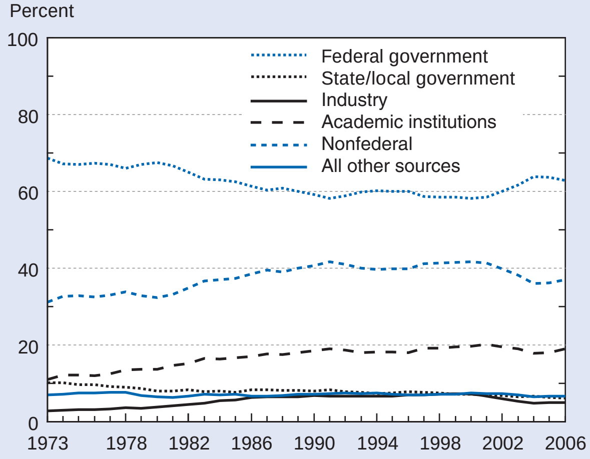


NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Academic Research and Development Expenditures: Fiscal Year 2006; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-2.

Science and Engineering Indicators 2008

Figure 5-5
Sources of academic R&D funding: 1973–2006



SOURCES: National Science Foundation, Division of Science Resources Statistics, Academic Research and Development Expenditures: Fiscal Year 2006; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-2.

Science and Engineering Indicators 2008

The share of support represented by institutional funds increased steadily between 1972 (12%) and 1991 (19%) but since then has remained fairly stable at roughly one-fifth of total funding. 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 funds 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 section "Patent-Related Activities and Income" later in this chapter for a discussion of patent and licensing income.)

- **State and local government funds.** State and local governments provided 6% ($3.0 billion) of academic R&D funding in 2006. Even though their absolute funding total continues to rise annually, the nonfederal government share has been slowly declining since its peak of 10.2% in 1972 to 1974. This share only reflects funds that state and local governments directly target to academic R&D activities.[5] 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.[6] Consequently, the actual contribution of state and local governments to academic R&D is not fully captured here, particularly for public institutions. (See chapter 8, "State Indicators," for some indicators of academic R&D by state.)
- **Industry funds.** After a 3-year decline between 2001 and 2004, industry funding of academic R&D increased for the second year in a row, to $2.4 billion in 2006. After reaching a high of 7% in 1999, industry's share has remained at 5% since 2003. Industrial support accounts for the smallest share of academic R&D funding, and support of academia has never been a major component of industry-funded R&D. (See appendix table 4-5 for time-series data on industry-reported R&D funding.)
- **Other sources of funds.** In 2006, other sources of support accounted for 7% ($3.2 billion) of academic R&D funding, a level that has stayed about the same since 1972. This category of funds includes grants and contracts 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.[7]

Expenditures by Field and Funding Source

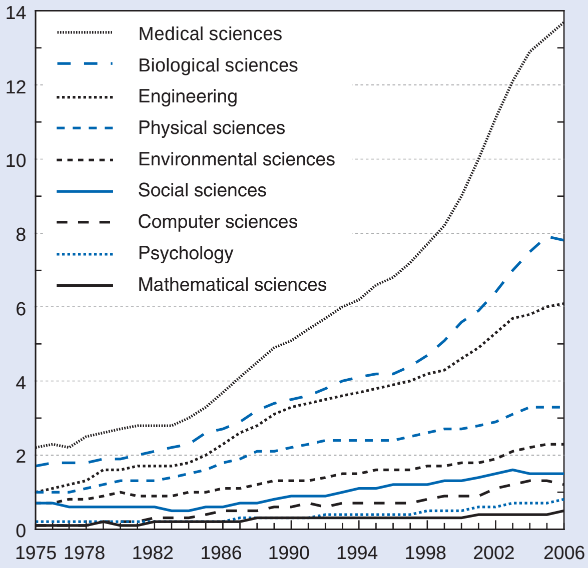
Examining and documenting academic R&D investment patterns across disciplines allows assessment of the funding balance in the academic R&D portfolio. For a discussion of non-S&E R&D expenditures see sidebar, "Non-S&E R&D." In 2006, the life sciences continued to receive the largest share of investment in academic R&D, accounting for roughly 60% of all expenditures and also of federal and nonfederal expenditures (appendix table 5-3). Within the life sciences, the medical sciences accounted for 33% of all academic R&D expenditures and the biological sciences accounted for another 19%.[8] The field of medical sciences has experienced the greatest increase in R&D investment over the past three decades. Between 1975 and 2006, R&D expenditures in the medical sciences grew from $2.2 billion to $13.7 billion in constant 2000 dollars (figure 5-6).

The distribution of academic R&D expenditures across the various broad S&E fields has remained relatively constant since 1975 (figure 5-7). The largest shifts between 1975 and 2006 were in the fields of life sciences (up 4.6 percentage points), engineering (up 3.6 percentage points), and social sciences (down 3.9 percentage points). More recently, however, between 1996 and 2006, only the life sciences and psychology (up 5.2 and 0.2 percentage points, respectively) saw their share of the academic R&D total increase.

More significant shifts in the relative shares of academic R&D expenditures occurred within the life sciences subfields. The medical sciences' share increased by 10 percentage points between 1975 and 2006, from 24% to 33%, and the share for agricultural sciences declined by 5 percentage points from 11% to 6% (appendix table 5-4).

The proportion of academic R&D expenditures funded by the federal government also varies significantly by field (appendix table 5-5). The field with the largest share of federal funding in 2006 was atmospheric sciences at 80%, followed by the fields of physics (75%), aeronautical/astronautical engineering (74%), and psychology (72%). The fields with the smallest shares of federal funding in 2006 were economics (35%), political science (34%), and agricultural sciences, which at 32% had the smallest share.

Figure 5-6
Academic R&D expenditures, by field: 1975–2006
Constant 2000 dollars (billions)



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Academic Research and Development Expenditures: Fiscal Year 2006; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-4.

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Non-S&E R&D

Beginning in 2003, the Survey of Research and Development Expenditures at Universities and Colleges has reported information at the institutional level on non-S&E R&D expenditures in addition to expenditures on S&E R&D. In 2003, 82% of the survey respondents provided data on R&D expenditures by non-S&E field, reporting a total of $1.4 billion in non-S&E R&D expenditures. In 2004, a slightly higher percentage of institutions provided data (85%), and the reported amount of non-S&E R&D expenditures increased to $1.6 billion. In 2005, the percentage of institutions providing these data increased to 94% and the reported amount of non-S&E R&D expenditures increased to $1.8 billion. Finally, 96% of institutions reported non-S&E R&D expenditures in 2006 totaling $1.9 billion (table 5-1). This amount is in addition to the $48 billion expended on S&E R&D. The largest amounts reported for individual non-S&E fields were in education ($817 million), business and management ($248 million), and humanities ($214 million). More than half of the federally financed non-S&E R&D expenditures (56.2%, or $435 million) were in the field of education.

Table 5-1
R&D expenditures in non-S&E fields at universities and colleges: FY 2006
(Millions of current dollars)

Field	All expenditures	Federal expenditures
All fields	1,880	773
Business and management	248	53
Communications/ journalism/library science	85	30
Education	817	435
Humanities	214	56
Law	68	28
Social work	90	40
Visual/ performing arts	46	4
Other non-S&E fields nec	313	128

nec = not elsewhere classified

NOTE: Detail may not add to total because some respondents reporting non-S&E R&D expenditures did not break out total and federal funds by non-S&E fields.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, Fiscal Year 2006.

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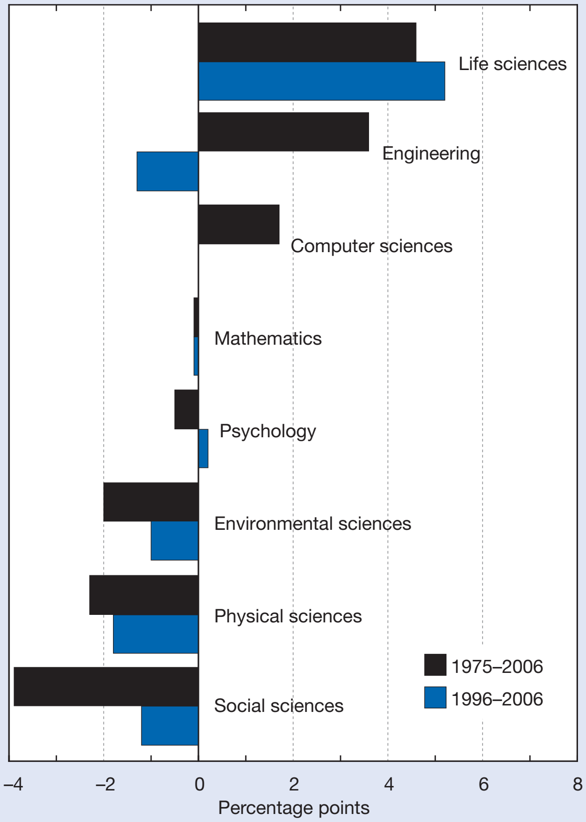
Figure 5-7
Changes in share of academic R&D in selected S&E fields: 1975–2006 and 1996–2006



NOTES: Fields ranked by change in share during 1975–2006, in descending order. Computer sciences' share identical in 1996 and 2006.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Academic Research and Development Expenditures: Fiscal Year 2006; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-4.

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The federally financed proportion of R&D spending declined in *all* of the broad S&E fields between 1975 and 1990 (appendix table 5-5).[9] However, since 1990, those declines have either stabilized or reversed, and the federal share reported in 2006 is higher than the 1990 share for all fields except mathematics, physical sciences, and sciences not elsewhere classified. Specifically, between 1998 and 2004, the period in which federal policies doubled the R&D budget of the National Institutes of Health (NIH), the broad fields of life sciences and psychology experienced the largest increases in their federally financed share of spending. During that period, the federal share for the life sciences increased from 57% to 64%, and the federal share for psychology increased from 67% to 75%.

Among the specific agency sources discussed in the next section, the Department of Health and Human Services (HHS), including NIH, provided the largest share of federal funding in FY 2006 ($17 billion), primarily in support of the medical and biological sciences (table 5-2). NSF provided the second largest amount of federal funding ($3.6 billion), with most (84%) going toward R&D in engineering and in the biological, computer, environmental, and physical sciences.

Federal Support of Academic R&D

The federal government continues to provide the majority of the funding for academic R&D.[10] Its overall contribution is the combined result of discrete funding decisions for several key R&D-supporting agencies with differing missions. Most of the funding provided by the federal government to academia reflects decisions arrived at through a competitive peer review process. Some of the funds are from long-established programs, such as those of the U.S. Department of Agriculture (USDA), that support academic research through formula funding rather than peer review, and other funds are the result of appropriations that Congress directs federal agencies to award to projects that involve specific institutions. Infrastructure support is often provided through user facilities in federal laboratories, such as those supported by the Department of Energy (DOE). Examining and documenting the funding patterns of the key funding agencies is important to understanding both their roles and that of the federal government overall. For a discussion of a major federal program with the objective of improving the geographical distribution of federal obligations for academic R&D, see sidebar, "EPSCoR: The Experimental Program to Stimulate Competitive Research."

Top Agency Supporters

Six agencies are responsible for most of the federal obligations for academic R&D, providing an estimated 95% of the $25 billion obligated in FY 2007 (appendix table 5-6). NIH provided an estimated 63% of total federal financing of academic R&D in 2007. An additional 13% was provided by NSF; 8% by the Department of Defense (DOD); 5% by the National Aeronautics and Space Administration (NASA); 3% by DOE; and 2% by the USDA.[11] Federal obligations for academic research (i.e., without the development component) are concentrated similarly to those for R&D (appendix table 5-7). Some differences exist, however, because some agencies place greater emphasis on development (e.g., DOD), whereas others place greater emphasis on research (e.g., NIH).

Total federal obligations for academic R&D in constant 2000 dollars, as well as those for DOE, NASA, NIH, and NSF, peaked in 2004 at $22.3 billion. Between 1990 and 2004, NIH's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 6.4% per year in constant 2000 dollars, increasing its share of federal funding from 52% to 63%. NASA and NSF experienced the next highest annual rates of growth during this period: 4.5% and 4.2%, respectively. Between 2004 and 2007, total obligations in constant dollars declined by an estimated 2% per year, and the decline occurred in all six major funding agencies.

Table 5-2

Federally financed academic R&D expenditures, by source of funds and S&E field: FY 2006

(Millions of current dollars)

Field	All expenditures	Federal expenditures	DOD	DOE	HHS	NASA	NSF	USDA	All other agencies
All fields	47,760	30,033	2,718	1,118	17,052	1,047	3,567	869	2,922
Computer sciences	1,438	1,015	295	36	47	25	427	2	115
Environmental sciences	2,602	1,763	158	91	64	247	566	59	552
Life sciences	28,831	18,268	446	153	15,204	103	587	718	1,008
Agricultural sciences	2,794	881	16	20	66	13	100	483	181
Biological sciences	9,044	6,240	153	66	5,033	44	426	179	306
Medical sciences	15,808	10,434	255	48	9,546	41	46	38	449
Life sciences nec	1,186	713	22	19	559	5	16	18	73
Mathematical sciences	530	373	37	11	79	4	183	3	28
Physical sciences	3,823	2,705	324	393	490	326	805	8	241
Psychology	875	629	33	4	468	12	49	1	58
Social sciences	1,703	711	38	13	288	11	100	37	222
Engineering	7,076	4,236	1,325	406	357	306	771	37	615

nec = not elswhere classified

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 = U.S. Department of Agriculture

NOTES: Not all fields reported in this table. Agency detail may not add to total because some institutions did not break out federal expenditures by agency.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, Fiscal Year 2006.

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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 (e.g., HHS and USDA in the life sciences and DOE in the physical sciences), whereas NSF, NASA, and DOD have more diversified funding patterns (figure 5-8; appendix table 5-8). Even though an agency may place a large share of its funds in one field, it may not be a leading contributor to that field, particularly if it does not spend much on academic research (figure 5-9).

In FY 2005, NSF was the lead federal funding agency for academic research in the physical sciences (36% of total funding); mathematics (50%); the computer sciences (71%); and the earth, atmospheric, and ocean sciences (39%) (appendix table 5-9). DOD was the lead funding agency in engineering (30%). HHS was the lead funding agency in the life sciences (91%), psychology (99%), and the social sciences (48%). Within the S&E subfields, other agencies took the leading role: DOE in physics (49%), the USDA in the agricultural sciences (99%), and NASA in astronomy (63%), aeronautical engineering (73%), and astronautical engineering (87%).

An Institutional Look at Academic R&D

The previous sections examined R&D for the entire academic sector. This section looks at some of the differences across institution types.

Funding for Public and Private Universities and Colleges

Although public and private universities rely on the same major sources to fund their R&D projects, the relative importance of those sources differs substantially for these two types of institutions (figure 5-10; appendix table 5-10). In 2006, public institutions received state and local government funding for approximately 8% of their total R&D expenditures ($2.7 billion of their $32.4 billion total), whereas only 2% ($0.3 billion) of private institutions' total R&D spending ($15.4 billion) was financed by state and local government. Compared with public institutions (23%, or $7.4 billion), private academic institutions also funded a much smaller portion of their R&D from institutional sources in 2006 (11%, or $1.6 billion). However, the federal government provided 75% ($11.6 billion) of the R&D funds spent by private institutions in 2006, compared with only 57% ($18.5 billion) for public institutions. The larger amount of institutional funds used for R&D at public institutions may reflect general-purpose state and local government funds that public institutions receive and can decide to use for R&D (although data on such breakdowns are not collected).[12] (For a more detailed discussion of the composition of institutional funds for public and private academic institutions, see sidebar, "Composition of Institutional Academic R&D Funds.")

Both public and private institutions received approximately 5% of their R&D support from industry in 2006. The share of total R&D expenditures funded by all other sources was also fairly comparable between public and private institutions, at 6% and 7%, respectively.

EPSCoR: The Experimental Program to Stimulate Competitive Research

EPSCoR, the Experimental Program to Stimulate Competitive Research, is based on the premise that universities and their S&E faculty and students are valuable resources that can potentially influence a state's development in the 21st century in much the same way that agricultural, industrial, and natural resources did in the 20th century.

EPSCoR originated as a response to a number of stated federal objectives. Section 3(e) of the National Science Foundation Act of 1950, as amended, states that "it shall be an objective of the Foundation to strengthen research and education in the sciences and engineering, including independent research by individuals, throughout the United States, and to avoid undue concentration of such research and education." Even earlier, the 1947 Steelman report, Science and Public Policy, in discussing the formation of NSF, stated *"it is clear that a portion of the funds expended by the National Science Foundation should be used to strengthen the weaker, but promising, colleges and universities, and thus to increase our total scientific potential"* (emphasis added).

But EPSCoR did not officially begin at NSF until 1978, when Congress authorized the agency to conduct EPSCoR in response to broad public concerns about the extent of geographical concentration of federal funding of R&D. Eligibility for EPSCoR participation was limited to those jurisdictions that have historically received lesser amounts of federal R&D funding and have demonstrated a commitment to develop their research bases and to improve the quality of S&E research conducted at their universities and colleges.

The success of the NSF EPSCoR programs during the 1980s subsequently prompted the creation of EPSCoR and EPSCoR-like programs in six other federal agencies: the Departments of Energy, Defense, and Agriculture; the National Aeronautics and Space Administration; the National Institutes of Health; and the Environmental Protection Agency. In FY 1993, congressional direction precipitated the formation of the EPSCoR Interagency Coordinating Committee (EICC). A memorandum of understanding (MOU) was signed by officials of the seven agencies with EPSCoR or EPSCoR-like programs agreeing to participate in the EICC. The major objective of the MOU focused on improving coordination among and between the federal agencies in implementing EPSCoR and EPSCoR-like programs consistent with the policies of participating agencies. The participating agencies agreed to the following objectives:

- Coordinate federal EPSCoR and EPSCoR-like programs to maximize the impact of federal support while eliminating duplication in states receiving EPSCoR support from more than one agency.
- Coordinate agency objectives with state and institutional goals, where appropriate, to obtain continued nonfederal support of science and technology (S&T) research and training.
- Coordinate the development of criteria to assess gains in academic research quality and competitiveness and in S&T human resource development.
- Furthermore, as members of the EICC, the agencies agreed to exchange information on pending legislation, agency policies, and relevant programs related to S&T research and training and, when appropriate, to provide responses on issues of common concern.

EPSCoR seeks to increase the R&D competitiveness of an eligible state through the development and utilization of the S&T resources residing in its major research universities. It strives to achieve its objective by (1) stimulating sustainable S&T infrastructure improvements at the state and institutional levels that significantly increase the ability of EPSCoR researchers to compete for federal and private sector R&D funding, and (2) accelerating the movement of EPSCoR researchers and institutions into the mainstream of federal and private sector R&D support.

In FY 2006, the seven EICC agencies spent a total of $353.4 million on EPSCoR or EPSCoR-like programs, up from $79.1 million in 1996, a more than fourfold increase (table 5-3). However, the Environmental Protection Agency discontinued issuing separate EPSCoR program solicitations in FY 2006, and NASA, which has 2-year money, planned for FY 2006 awards but had not yet made its selections. Twenty-seven states, the U.S. Virgin Islands, and the Commonwealth of Puerto Rico currently participate in the combined agency EPSCoR and EPSCoR-related programs, although not every state is included in each agency's set of EPSCoR states (table 5-4).

(continued on next page)

Table 5-3

EPSCoR and EPSCoR-like program budgets, by agency: FY 1996–2006

(Millions of dollars)

Agency	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
All agencies	79.1	80.9	74.1	91.0	129.7	209.2	270.7	353.9	351.5	365.7	353.4
DOD	18.6	16.2	18.0	19.0	24.0	18.7	15.7	15.7	8.4	11.4	11.5
DOE	6.5	6.3	6.8	6.8	6.8	7.7	7.7	11.7	7.7	7.6	7.3
EPA	NA	2.5	2.5	2.5	NA	NA	NA	NA	2.5	2.4	0.0
NASA	5.0	4.6	5.0	5.0	8.9	9.2	8.8	9.2	8.6	10.8	0.0
NIH	2.2	1.9	5.0	10.0	40.0	100.0	160.0	210.0	214.0	222.0	220.0
NSF	35.7	38.4	36.8	47.7	50.0	73.6	78.5	87.9	93.3	92.9	96.6
USDA	11.1	11.0	NA	NA	NA	NA	NA	19.3	17.0	18.6	18.0

NA = not available

DOD = Department of Defense; DOE = Department of Energy; EPA = Environmental Protection Agency; EPSCoR = Experimental Program to Stimulate Competitive Research; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = U.S. Department of Agriculture

NOTES: EPA discontinued issuing separate EPSCoR program solicitations in FY 2006. NASA plans for FY 2006 awards, but no selections yet made. NASA has 2-year money.

SOURCES: 1998–2006 data for DOE, NASA, NIH, NSF, and USDA provided by agency EPSCoR representatives (USDA 2003–05 data from agency website); 2004–06 data for EPA taken from DOE website, EPSCoR Funding by Agency; 2000–06 data for DOD from DOD news releases; 1996–97 data for all agencies and 1998 and 1999 data for DOD and EPA from National Science Board, Science and Engineering Indicators 2000, table 6-1.

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Table 5-4

EPSCoR and EPSCoR-like program budgets, by agency and state: FY 2006

(Thousands of dollars)

State	DOD	DOE	NASA	NIH	NSF	USDA
Alabama	0	685	442	0	5,437	1,142
Alaska	981	0	0	3,669	3,518	0
Arkansas	350	135	538	7,305	2,956	3,971
Connecticut	0	0	314	0	0	0
Delaware	0	0	0	10,131	4,962	281
Hawaii	0	0	0	4,304	6,083	770
Idaho	0	375	633	7,109	3,450	0
Kansas	450	135	442	14,085	4,980	0
Kentucky	0	0	825	15,135	3,901	1,523
Louisiana	0	462	564	20,637	6,523	764
Maine	0	0	529	8,178	3,542	200
Mississippi	0	132	258	9,103	3,695	0
Montana	838	455	588	9,303	4,091	0
Nebraska	1,110	265	825	11,682	4,388	0
Nevada	772	740	825	7,622	4,020	0
New Hampshire	424	0	0	4,646	403	0
New Jersey	0	0	0	0	0	2,679
New Mexico	0	135	0	7,329	3,558	0
North Dakota	468	923	250	6,740	3,237	801
Oklahoma	1,236	350	622	15,727	5,690	1,462
Puerto Rico	574	375	449	3,484	743	0
Rhode Island	400	0	0	11,182	3,306	0
South Carolina	500	660	425	11,613	5,205	1,034
South Dakota	570	125	637	6,833	2,510	201
Tennessee	829	140	0	0	1,726	0
U.S. Virgin Islands	0	0	0	0	894	0
Vermont	1,179	0	633	10,255	828	1,041
West Virginia	350	855	422	9,343	3,374	1,208
Wyoming	482	140	543	4,571	3,601	923

DOD = Department of Defense; DOE = Department of Energy; EPSCoR = Experimental Program to Stimulate Competitive Research; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = U.S. Department of Agriculture

NOTES: FY 2005 NASA data; NASA plans for FY 2006 awards, but no selections yet made. The Environmental Protection Agency discontinued issuing separate EPSCoR program solicitations in FY 2006, so no state level data available for 2006. DOE state level data do not add to total because $193,000 allocated to technical support and not distributed to states.

SOURCE: Data provided by agency EPSCoR representatives.

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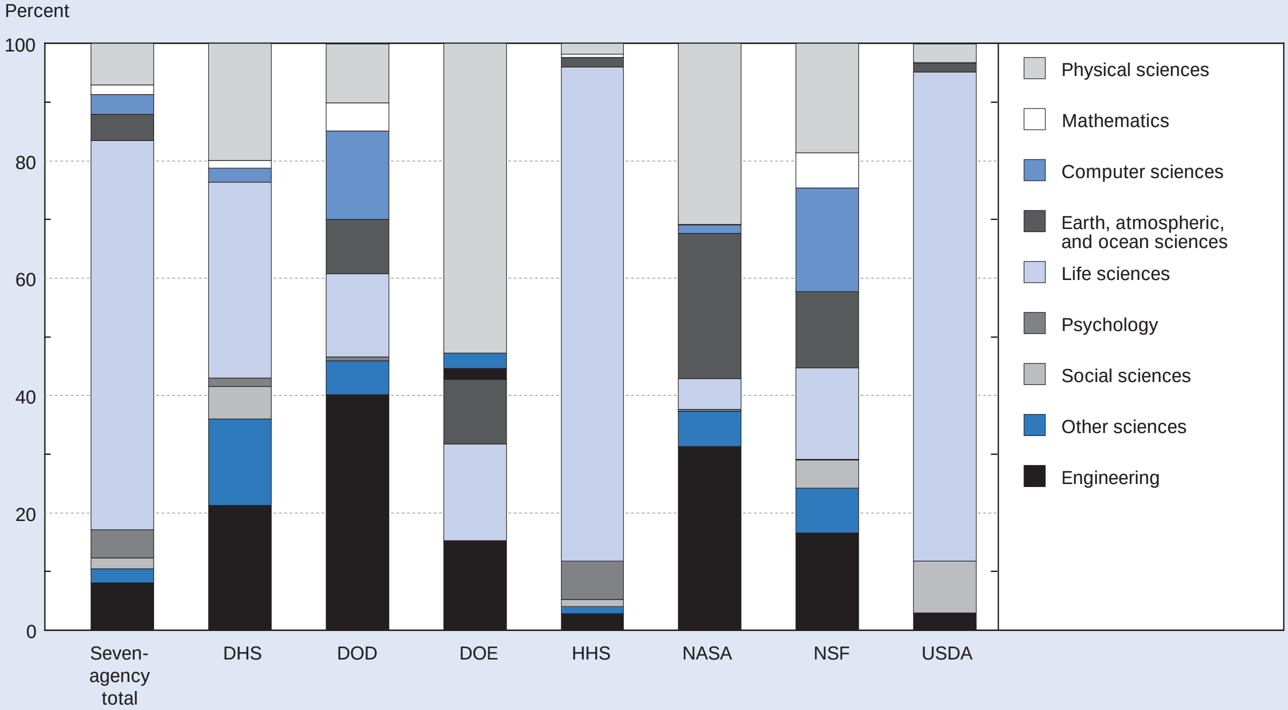
Figure 5-8
Federal agency academic research obligations, by field: FY 2005



DHS = Department of Homeland Security; 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 = U.S. Department of Agriculture

NOTE: Agencies reported represent approximately 97% of federal academic research obligations.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Federal Funds for Research and Development: Fiscal Years 2005, 2006, and 2007 (forthcoming). See appendix table 5-8.

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Distribution of R&D Funds Across Academic Institutions

Of the 650 institutions that reported R&D expenditures of at least $150,000 in 2006, the top 20 in terms of total R&D expenditures accounted for 30% of total academic R&D spending. The top 100 institutions accounted for 80% of all academic R&D expenditures in 2006. Appendix table 5-11 presents a detailed breakdown of the distribution among the top 100 institutions.

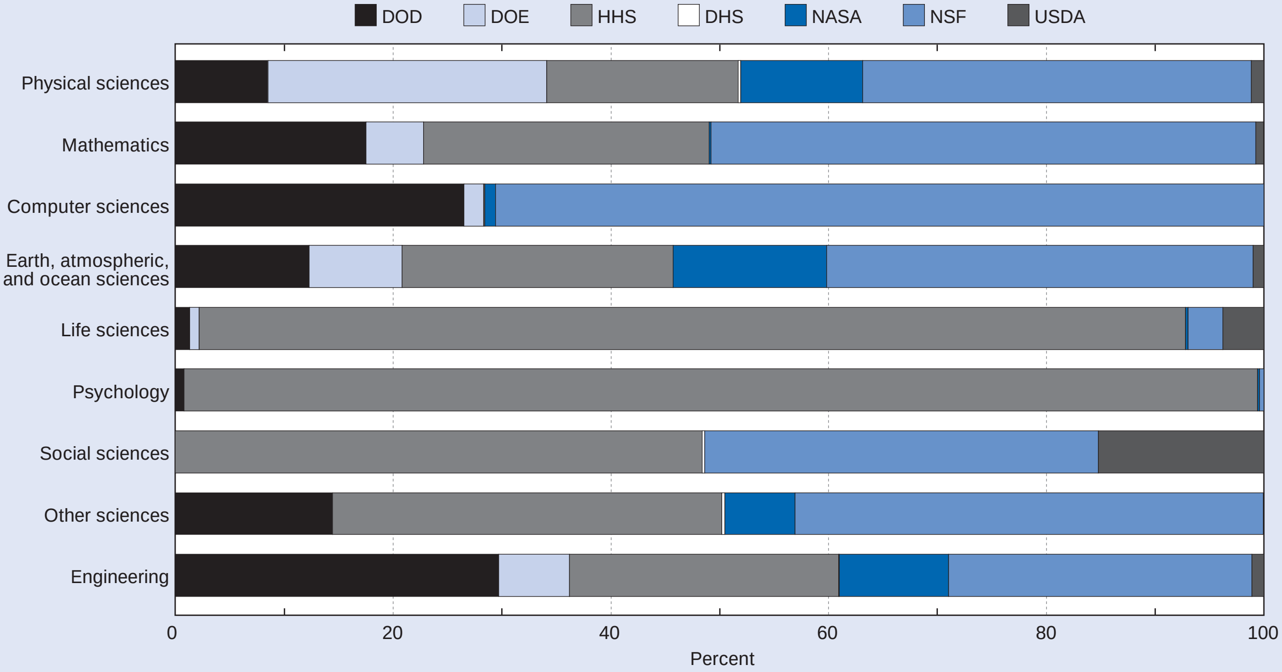
The concentration of academic R&D funds among the top 100 institutions has stayed relatively constant over the past two decades (figure 5-11). In 1986, institutions not in the top 100 accounted for 17% of the nation's total academic R&D expenditures. This percentage increased to 20% in 1993 and remained at that level through 2006. The share held by the top 10 institutions has also fluctuated narrowly (between 17% and 20%) throughout this 20-year period.

It should be noted that the composition of the universities in each of these groups is not the same over time; mobility occurs between groups as universities increase or decrease their R&D activities. Three of the top 10 institutions in 1986 were not in the top 10 in 2006, and 5 of the top 20 institutions in 1986 were not in the top 20 in 2006. The next section points to an increasing number of academic institutions receiving federal support for their R&D activities between 1972 and 2005.

Spreading Institutional Base of Federally Funded Academic R&D

The number of academic institutions receiving federal support for their R&D activities increased fairly steadily between 1971 and 1994, when it reached a peak of 902 institutions. Between 1995 and 2005, the number of institutions receiving federal support fluctuated between 789 and 891 (figure 5-13).[13] Both the growth through 1994 and the fluctuations since then almost exclusively affected institutions that were not classified as having very high or high research activity by the Carnegie Foundation for the Advancement of Teaching. The number of such institutions receiving federal support almost doubled between 1971 and 1994, rising from 375 to 707. It then dropped to 593 in 1999 before beginning to rise again over the past several years (appendix table 5-12). These institutions' share of federal support also increased between 1971 and 2005, from 11% to 18%.

Figure 5-9
Major agency field shares of federal academic research obligations: FY 2005



DHS = Department of Homeland Security; 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 = U.S. Department of Agriculture

NOTE: Agencies reported represent approximately 97% of federal academic research obligations.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Federal Funds for Research and Development: Fiscal Years 2005, 2006, and 2007 (forthcoming). See appendix table 5-9.

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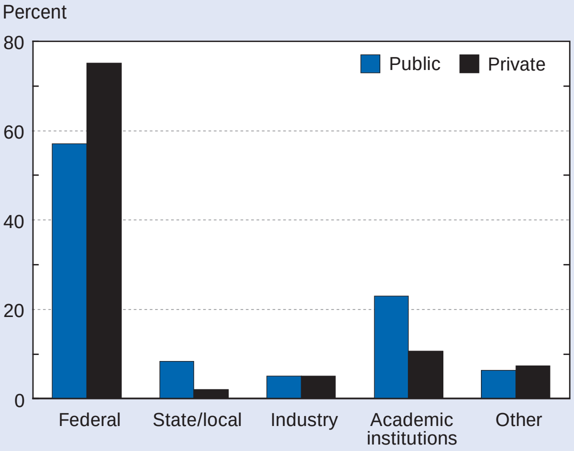
Figure 5-10
Sources of academic R&D funding for public and private institutions: 2006



SOURCES: National Science Foundation, Division of Science Resources Statistics, Academic Research and Development Expenditures: Fiscal Year 2006; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-10.

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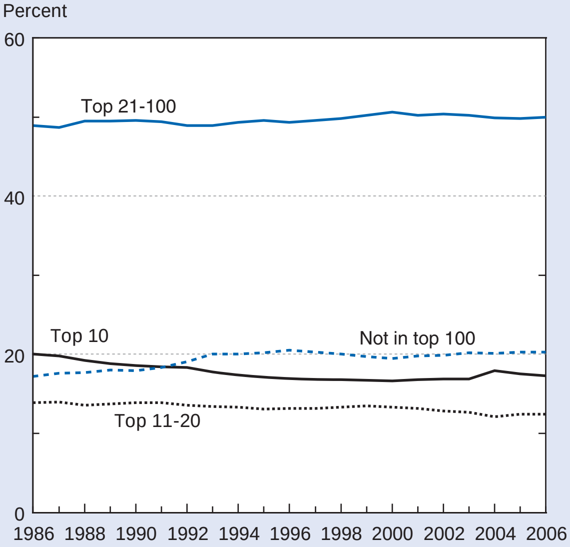
Figure 5-11
Share of academic R&D, by rank of university and college academic R&D expenditures: 1986–2006



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations (2007). See appendix table 5-11.

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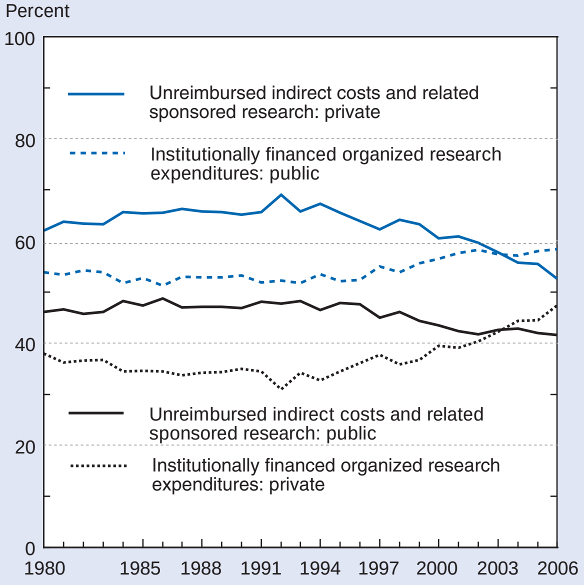
Composition of Institutional Academic R&D Funds

In 2006, academic institutions committed a substantial amount of their own resources to R&D: roughly $9.1 billion or 19% of all funding for academic R&D. The share of institutional support for academic R&D at public institutions (23%) was greater than that at private institutions (11%) (appendix table 5-10). 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 most of the 1990s, institutional R&D funds were divided roughly equally between two components: (1) institutionally financed organized research expenditures and (2) unreimbursed indirect costs and related sponsored research. The balance shifted toward the former after 1998 as the latter share began to decline for both types of institutions. 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 53% to 69% of private institutions' own R&D funds were designated for unreimbursed indirect costs plus cost sharing, compared with 42% to 49% of public institutions' own funds (figure 5-12).

Figure 5-12
Components of institutional R&D expenditures for public and private academic institutions: 1980–2006



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations (2007).

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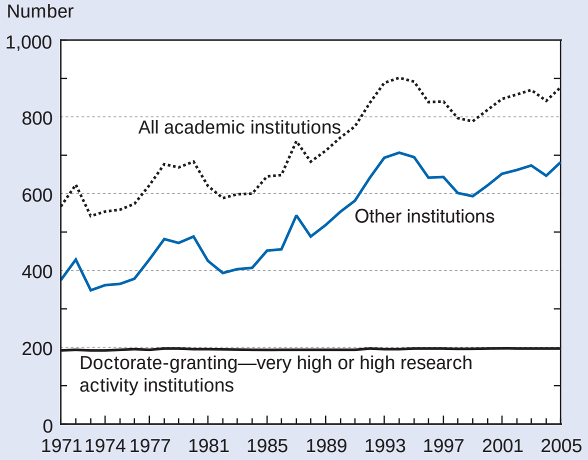
Figure 5-13
Academic institutions receiving federal R&D support, by selected Carnegie classification: 1971–2005



NOTE: Institutions designated by 2005 Carnegie classification code. Other institutions include all institutions except very high and high research activity institutions. For information on these institutional categories, see chapter 2 sidebar, "Carnegie Classification of Academic Institutions," and The Carnegie Classification of Institutions of Higher Education, http://www.carnegiefoundation.org/classifications/index.asp, accessed 17 August 2007.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions: FY 2005 (forthcoming); and Integrated Science and Engineering Resources Data System (WebCASPAR), http://webcaspar.nsf.gov.

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Academic R&D Equipment

Research equipment is an integral component of the academic R&D enterprise. This section examines expenditures on research equipment, the federal role in funding these expenditures, and the relation of equipment expenditures to overall R&D expenditures.

Expenditures

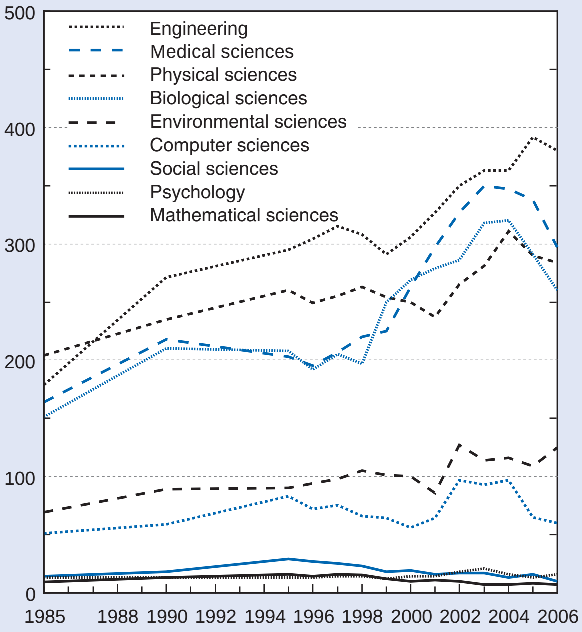
In 2006, about $1.8 billion in current funds was spent for academic research equipment. About 83% of these expenditures were concentrated in three fields: the life sciences (41%), engineering (24%), and the physical sciences (18%) (appendix table 5-13). After more than doubling in constant 2000 dollars between 1985 and 2004, equipment expenditures in the life sciences subfields of medical and biological sciences declined in 2005 and 2006. Engineering equipment expenditures also doubled between 1985 and 2005 but declined in 2006 (figure 5-14).

Federal Funding

Federal funds for research equipment are generally received either as part of research grants or as separate equipment grants, depending on the funding policies of the particular federal agencies involved. The share of federal funding for research equipment varies significantly by field.

Figure 5-14
Current fund expenditures for research equipment at academic institutions, by field: 1985–2006

Constant 2000 dollars (millions)



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Academic Research and Development Expenditures: Fiscal Year 2006; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-13.

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In 2006, sociology received federal funding for 29% of its research equipment expenditures. In contrast, federal funding accounted for 82% of equipment expenditures in the field of astronomy (appendix table 5-14). The share of total expenditures for research equipment funded by the federal government fluctuated between 56% and 64% during the 1985–2006 period.

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 proportion has been declining steadily since reaching a peak of 7% in 1985. By 2006, it had declined to 4% (appendix table 5-15). R&D equipment intensity in 2006 was highest in the physical sciences (9%) and certain engineering subfields (about 8% in both mechanical and metallurgical/materials engineering). The field of computer sciences experienced the most significant decline in research equipment intensity between 1985 and 2006, falling from 13% to 5%, which may reflect strong declines in equipment prices in this technology area and growth in capability of more general-purpose infrastructure.[14]

Academic R&D Infrastructure

The physical infrastructure of academic institutions is critical to supporting R&D activities. Traditional indicators of the status of the research infrastructure are the amount of research space currently available and the amount of investment in future facilities.

In addition to the traditional "bricks and mortar" research infrastructure, "cyberinfrastructure" is playing an increasingly important role in the conduct of S&E research. Technological advances are significantly changing S&E research methods. In some cases, advanced technology is already changing the role of traditional bricks and mortar facilities. According to the NSF Advisory Panel on Cyberinfrastructure, these advances are not simply changing the conduct of science but are revolutionizing it (NSF 2003). The panel defined *cyberinfrastructure* as the "infrastructure based upon distributed computer, information and communication technology" (NSF 2003, p 1.2). The report discusses the current and potential future importance of cyberinfrastructure, stating that "digital computation, data, information and networks are now being used to replace and extend traditional efforts in science and engineering research" (NSF 2003, p 1.1).

How the relationship between cyberinfrastructure and traditional bricks and mortar infrastructure will develop is unknown. For example, access to high-quality research facilities may become available to researchers located at institutions where traditional research space has not been available. Some institutions have begun conducting research not in their own laboratories or research facilities but through networking and/or high-performance computing, communicating with research facilities thousands of miles away or accessing very large databases generated by advanced data collection technologies.

Bricks and Mortar

Research Space. Research-performing colleges and universities[15] continued to expand their stock of research space in FY 2005, but at a significantly slower rate than the previous 2-year period (table 5-5). Institutions reported a 7% increase in the amount of research space between FY 2003 and FY 2005, for a total of approximately 185 million net assignable square feet (NASF).[16] The size of this increase was more similar to the rates of previous biennial increases than to the 11% increase between FY 2001 and FY 2003, which was the highest biennial increase since the survey began collecting data.

In FY 2005, research space increased in all S&E fields except the earth, atmospheric, and ocean sciences, which experienced a 3% decline. Additionally, for the first time in more than a decade, the amount of research animal space declined.

Two of the three fields of science that experienced the largest percentage of increase in research space in FY 2003 again had the largest percentage of increase in FY 2005: the computer sciences and medical sciences. From a relatively modest base, the computer sciences had the largest increase

(32%), which resulted in 4.1 million NASF. In the decade between 1996 and 2005, space for the computer sciences grew by 105%.

During the same period, research space in psychology, the social sciences, mathematics, and the medical sciences also increased by more than 50%. However, except for the medical sciences, all of these fields also have the smallest amount of total space relative to the other fields. Between 1996 and 2005, the physical sciences and earth, atmospheric, and ocean sciences experienced the least amount of growth in research space.

Since survey inception, the greatest increases in research space have occurred in the biological sciences and medical sciences. The proportion of total space dedicated to these two fields has remained fairly stable from year to year, ranging between 38% and 42%. However, in 2005, the medical sciences surpassed the biological sciences in research space for the first time (39.7 million NASF versus 38.5 million NASF, respectively).

Construction of Research Space. Total new S&E research space being constructed in FY 2004–05 was also dominated by the biological and medical sciences. Sixty-four percent of newly built research space and 67% of construction funds were in the biological and medical sciences (tables 5-6 and 5-7). The trend continued in FY 2006–07. Fifty-four percent of all new construction and 57% of all expenditures for this construction are planned for these two fields.[17] However, whereas the largest percentage of new research space is planned for the biological and medical sciences, the physical and social sciences are expected to experience the largest rate of increase, about 200%.

Institutions anticipated a decline in the amount of newly constructed research space in the earth, atmospheric, and ocean sciences in FY 2006–07. This follows an absolute decline in space in this field during the previous 2-year period. The field of earth, atmospheric, and ocean sciences is the only one that experienced a decline in NASF since FY 2003–05 and the only field that anticipated a decline in new construction in FY 2006–07.

Total dollars invested in new construction of research space declined in FY 2005 for the first time in a decade, by 17% to $6.1 billion (table 5-7). This decline may be temporary, however, as institutions anticipate an increase in FY 2006–07 in funds expended for planned new construction. Even with the decline, however, total dollars for construction of new research space almost doubled between FY 1999 and FY 2005.

As a share of total expenditures for new construction, only the biological and medical sciences experienced an increase between FY 1987–88 and FY 2004–05, from 23% to 33% for the biological sciences and from 25% to 34% for the medical sciences. Psychology and mathematics remained about the same while all other fields experienced a decline. Institutions estimated that by FY 2006–07, the share of new construction for the biological sciences would decline to 29% and the share for the medical sciences to 28%. The share of total expenditures for research space in the earth, atmospheric, and ocean sciences ($69 million) was estimated to decline to less than 1%. The largest percentage point increase in share of funds for new construction in FY 2006–07 was estimated for the physical sciences (from 7% to 10%).

Table 5-5

S&E research space in academic institutions, by field: FY 1988–2005

(Millions of net assignable square feet)

Field	1988	1990	1992	1994	1996	1998	1999	2001	2003	2005
All fields	112	116	122	127	136	143	148	155	172.7	185.1
Agricultural sciences	18	21	20	20	22	25	24	27	26.4	26.8
Biological sciences	24	27	28	28	30	31	31	33	36.0	38.5
Computer sciences	1	1	2	2	2	2	2	2	3.1	4.1
Earth, atmospheric, and ocean sciences	6	6	7	7	7	8	8	8	8.9	8.6
Engineering	16	17	18	21	22	23	24	26	27.4	28.9
Mathematics	1	1	1	1	1	1	1	1	1.5	1.6
Medical sciences	19	20	22	23	25	25	26	28	34.9	39.7
Physical sciences	16	16	16	17	18	18	19	19	20.4	21.0
Psychology	3	3	3	3	3	3	4	4	4.4	4.8
Social sciences	3	3	3	3	4	5	3	5	5.7	6.3
Other sciences	4	2	2	2	2	3	3	3	3.8	4.9
Animal research space	NA	NA	9	11	12	12	13	NA	16.7	16.5

NA = not available

NOTES: Animal research space listed separately and also included in individual field totals. NA indicates years question not asked. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 1988–2005.

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Table 5-6
New construction of S&E research space in academic institutions, by field and time of construction: FY 2004–07
(Millions of square feet)

Field	Construction started FY 2004–05		Construction planned to start FY 2006–07	
	Institutions (number)	Total NASF	Institutions (number)	Total NASF
All fields	167	10.2	172	13.7
Agricultural sciences	26	0.4	23	0.5
Biological sciences	84	3.2	77	3.4
Computer sciences	18	0.3	14	0.5
Earth, atmospheric, and ocean sciences	26	0.3	14	0.1
Engineering	50	1.5	47	1.9
Mathematics	8	*	7	0.1
Medical sciences	57	3.3	54	4.0
Physical sciences	32	0.5	43	1.5
Psychology	14	0.2	10	0.2
Social sciences	12	0.1	11	0.3
Other sciences	12	0.3	23	1.2
Animal research space	64	1.2	54	1.0

* = >0 but <50,000 NASF

NASF = net assignable square feet

NOTES: Animal research space listed separately and also included in individual field totals. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Year 2005.

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Table 5-7
Costs for new construction of S&E research space in academic institutions, by field: Selected years, FY 1986–2007
(Millions of dollars)

Field	1986–87	1988–89	1990–91	1992–93	1994–95	1996–97	1998–99	2002–03	2004–05	2006–07
All fields	2,051	2,464	2,976	2,812	2,768	3,110	3,222	7,388.7	6,109.9	7,903.4
Agricultural sciences	150	152	175	210	150	273	224	142.3	171.5	135.6
Biological sciences	463	577	832	633	614	582	781	1,944.7	2,022.0	2,327.9
Computer sciences	61	65	40	47	46	21	75	338.4	122.0	314.6
Earth, atmospheric, and ocean sciences	57	82	170	123	33	172	149	194.2	121.6	69.2
Engineering	430	388	395	286	575	332	416	1,055.3	890.8	1,079.8
Mathematics	2	8	12	10	2	9	13	9.3	15.6	20.3
Medical sciences	505	648	807	999	647	1,043	881	2,256.0	2,075.0	2,183.6
Physical sciences	182	401	430	337	426	381	419	782.4	398.9	756.1
Psychology	23	25	36[a]	16	42	77	49	73.3	91.7	108.2
Social sciences	38	48	NA	44	112	75	55	148.4	78.9	150.7
Other sciences	139	70	79	106	122	145	159	444.4	121.9	757.5
Animal research space	NA	NA	NA	NA	NA	NA	223	731.9	660.0	742.9

NA = not available, question not asked

[a] Psychology and social sciences not differentiated in questionnaire item for FY 1990–91.

NOTES: Animal research space listed separately and also included in individual field totals. Question on construction costs not asked on FY 2001 survey; therefore, no data reported. Only construction projects costing >$250,000 for a single field reported on FY 2003 and FY 2005 surveys; construction projects costing >$100,000 reported in previous cycles. 2006–07 data estimates of planned research space. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 1988–2005.

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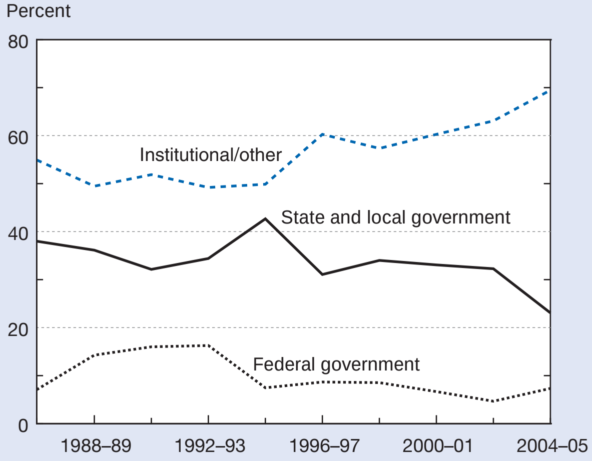
Source of Funds. Institutions use one or more sources to fund their capital projects, including the federal government, state or local governments, and the institutions' own funds (appendix table 5-16).[18] The federal government's share of total construction funding, never a large proportion, reached its smallest proportion (5%) of total construction funds in FY 2002–03 (figure 5-15).[19] Concurrently, the institutional share of construction funds generally increased during this time and reached its highest share, 63%, in FY 2002–03.

Between FY 2002–03 and FY 2004–05, the federal share increased for the first time since FY 1994–95, rising from 5% to 7%. During the same period, the share of construction funds from state and local governments decreased by 9 percentage points to 23% in FY 2004–05. This was the largest percentage point decline in the state and local share since FY 1986–87, except for the 2-year period from FY 1994 to FY 1996, when the decrease was also 9 percentage points. Institutions generally accommodated this decrease in state and local funds by increasing the institutional share of funds and decreasing their total expenditures. During FY 2004–05, the institutional share rose to the highest percentage of total funds for construction (69%) since FY 1986–87. During this period, the institutional share of funds expended on repair/renovation also increased to its highest percentage since FY 1986–87.

Cyberinfrastructure: Networking

Networking resources are a key component of cyberinfrastructure.[20] Networks allow researchers to communicate and transfer data both within a specific institution's boundaries and with others around the world. At many institutions, the same networks are used for multiple academic functions such as instruction, research, and administration.[21]

Figure 5-15
Source of funds for new construction of S&E research space: 1986–87 to 2004–05



NOTE: Data extrapolated for 2000–01 because data not collected.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 1986–2003. See appendix table 5-16.

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All academic institutions today have connections to the *commodity Internet* (Internet1), the network commonly known as the Internet. Although Internet connections are used for many purposes (e-mail, buying books from the campus bookstore, transfer of databases), conducting research can require greater network capabilities than other activities.

One common indicator of network capability is bandwidth, or speed. A network's bandwidth can affect the amount and type of research activity accomplished through the network. The greater the amount of bandwidth, the more capable the network is in handling both large amounts of data and communication traffic and more demanding or sophisticated communications. Although a slow network connection might well be able to transmit scientific articles, accessing scientific instruments and databases located thousands of miles away demands (among other requirements) higher bandwidth.

Internet Bandwidth. In FY 2005, 43% of academic institutions reported the total of their commodity internet (Internet1) and Abilene (often called Internet2) bandwidth to be

Table 5-8
Bandwidth to commodity Internet (Internet1) and Abilene (Internet2) at academic institutions: FY 2005 and 2006
(Percent distribution)

Bandwidth	FY 2005	FY 2006
All bandwidth	100	100
<1.6 mb	2	1
1.6–9 mb	3	2
10 mb	1	*
11–45 mb	23	18
46–99 mb	16	13
100 mb	3	4
101–155 mb	9	10
156–622 mb	18	17
623–999 mb	3	4
1–2.5 gb	15	20
2.6–9 gb	4	5
10 gb	*	1
>10 gb	2	4
Other	*	*
Institutions (number)	449	449

* = >0 but <0.5%
gb = gigabits/second; mb = megabits/second

NOTES: Abilene is a high-performance backbone network that enables the development of advanced Internet applications and the deployment of leading-edge network services to member colleges, universities, and research laboratories across the country. Detail may not add to total because of rounding. FY 2006 data estimated.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Year 2005.

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greater than 155 megabits (table 5-8). Twenty-one percent reported bandwidth of 1 gigabit or greater. The percentage of institutions with total bandwidth of 1 gigabit or faster is estimated to increase about 9 percentage points in FY 2006 to 30%.

High-Performance Network Connections. In addition to their Internet1 connections, institutions may also be connected to one or more high-performance networks. By FY 2005, the majority of institutions had connected to Abilene, a high-performance network dedicated to research led by a consortium of universities, governments, and private industry; only 5% of doctorate-granting institutions did not have an Abilene connection. By FY 2006, 76% of all institutions anticipated having a connection, a 17% increase since FY 2003. Furthermore, 32% of those anticipating Abilene connections in FY 2006 also anticipated Abilene bandwidth of 1 gigabit or faster.

Institutions may also be connected to the National Lambda Rail, a national fiber optic infrastructure supporting multiple networks for the research community. In just 1 year, the number of institutions connected to the National Lambda Rail is expected to increase by 200%, from 10% with connections in FY 2005 to 31% in FY 2006.[22] Finally, about 13% of institutions anticipated being connected to at least one federal government high-performance network, such as NASA's Research and Engineering Network (NREN) or DOE's Energy Sciences Network (ESnet), by FY 2006.

The majority of institutions (63%) obtained at least some of their bandwidth, whether Internet1 or high performance, through a consortium in FY 2005, and additional institutions anticipated doing so in FY 2006 (68%). All but one of the institutions reporting Internet1 connections of 1 gigabit or faster received their bandwidth through a consortium. Although institutions reported a variety of consortia, many are state and/or regional research and education networks. For example, the list of consortia includes the Metropolitan Research and Education Network (MREN), the Corporation for Education Network Initiatives in California (CENIC), Merit Network, and the New York State Education and Research Network (NYSERNet).

Internal Institutional Networks. Concurrent with increasing connection speeds to external networks such as Internet1, institutions are also increasing their internal network speeds (table 5-9). In FY 2003, the highest speed from one desktop to another was 100 megabits at 64% of institutions and 1–2.5 gigabits at 33%. By FY 2005, only 40% of institutions reported 100 megabits as their highest desktop-to-desktop speed, and 54% reported speeds of 1 gigabit or faster. In FY 2003, no institution had a speed greater than 2.5 gigabits, whereas 4% had speeds at least this fast in FY 2005; more than 14% of institutions estimated that their highest desktop-to-desktop speed would be at least this fast in FY 2006.

Table 5-9

Highest desktop-to-desktop speed on an academic institution's internal network: FY 2003, 2005, and 2006

(Percent distribution)

Connection speed	FY 2003	FY 2005	FY 2006
All connection speeds	100	100	100
<1.6 mb	*	0	0
1.6–9 mb	0	0	0
10 mb	2	*	0
11–45 mb	0	*	*
46–99 mb	0	2	1
100 mb	64	40	28
101–155 mb	*	*	*
156–622 mb	*	1	1
623–999 mb	0	3	3
1–2.5 gb	33	50	53
2.6–9 gb	0	1	2
10 gb	0	3	11
>10 gb	0	*	1
Other	0	0	0
Institutions (number)	425	449	449

* = >0 but <0.5%

gb = gigabits/second; mb = megabits/second

NOTE: Detail may not add to total because of rounding. FY 2006 data estimated.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 2003 and 2005.

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Doctoral Scientists and Engineers in Academia

The role of research in U.S. universities is both to create new knowledge and to educate students who will become the future generations of researchers and teachers (Association of American Universities 2006). Doctoral scientists and engineers in academia, and in particular faculty in U.S. colleges and universities, are an important aspect of academic R&D, as they generally engage in both research and teaching. The focus of this section is on the research aspects of doctoral scientists and engineers in academia. Teaching aspects of faculty employment are more thoroughly covered in chapter 2.

This section examines trends in employment and research activity of doctoral scientists and engineers in U.S. universities and colleges, with special attention paid to faculty in research universities. Research universities have a disproportionate influence on the U.S. academic R&D enterprise. Research institutions, although few in number, are the leading producers of S&E bachelor's, master's, and doctoral degree recipients (see chapter 2) and the doctorate-granting source of more than three-quarters of faculty with S&E doctorates (NSF/SRS 2006). These institutions also conduct more than

80% of academic R&D (as measured by expenditures) and produce the bulk of both academic articles and patents (see section "Outputs of S&E Research: Articles and Patents" later in this chapter).

Trends in Academic Employment of Doctoral Scientists and Engineers

Academic employment of S&E doctorate holders reached a record high of 274,200 in 2006 (appendix table 5-17).[23] However, long-term growth in the number of these positions between 1973 and 2006 was slower than in either business or government. Employment in the academic sector slowed in the 1990s, especially at research universities, and growth over the past three decades was slower than in the business and government sectors (table 5-10; figure 5-16). As a result, the share of all S&E doctorate holders employed in academia dropped from about 55% to 45% during the 1973–2006 period (table 5-11). Beginning in the 1990s, the share of those with recently awarded degrees (that is, a degree awarded within 3 years of the survey year) employed in academia was generally substantially higher than the overall academic employment share for S&E doctorate holders, possibly reflecting the relatively large number of young doctorate holders in postdoc positions. In 2006, more than half of recent doctorate holders were employed in academia.

All Academic S&E Doctoral Employment

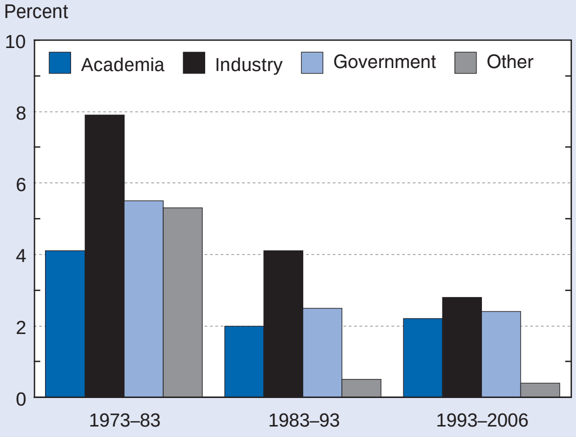
Growth in academic employment was stronger for life scientists than for other scientists and engineers. In engineering and many other science fields, growth in academic employment slowed in the early 1990s, but increased from 1995 to 2006 (figure 5-17; appendix table 5-17).

Trends in academic employment of S&E doctorate holders suggest continual movement away from the full-time faculty position as the academic norm (figure 5-18). Although academic employment of S&E doctorate holders grew from 118,000 in 1973 to 274,200 in 2006 (appendix table 5-17), during this period, full-time faculty positions increased more slowly than postdoc and other full- and part-time positions.

Table 5-12 shows the resulting distribution of academic employment of S&E doctorate holders. The full-time faculty share was 72% of all academic employment in 2006, down from 88% in the early 1970s. These employment trends, particularly during the 1993–2006 period, occurred as real spending for academic R&D rose by 73%, retirement of faculty who were hired during the 1960s increased, and academic hiring of young doctorate holders showed a modest rebound.[24]

Nonfaculty ranks (i.e., full- and part-time adjunct faculty, lecturers, research associates, administrators, and postdocs) increased from 41,400 in 1993 to 76,600 in 2006. This 85% increase stood in sharp contrast to the 15% rise in the number of full-time faculty. Both the full-time nonfaculty and part-time components grew between 1993 and 2006. The number of postdocs rose more slowly during most of this period, remaining at 16,000–19,000 from 1995 to 2003 before increasing to about 23,000 in 2006.[25] Part-time employees accounted for only a small share (between 2% and 4%) of all academic S&E doctoral employment throughout most of the period before rising to almost 6% in 2006 (appendix table 5-17).

Figure 5-16
Average annual growth rate for employment of S&E doctorate holders: 1973–2006



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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Table 5-10
Average annual growth rate for employment of S&E doctorate holders in U.S. economy: 1973–2006
(Percent)

Sector	1973–2006	1973–83	1983–93	1993–2006
All sectors	3.3	5.4	2.5	2.2
Academia	2.7	4.1	2.0	2.2
Industry	4.7	7.9	4.1	2.8
Government	3.4	5.5	2.5	2.4
Other	1.9	5.3	0.5	0.4

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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Table 5-11
S&E doctorate holders employed in academia, by years since doctorate: Selected years, 1973–2006
(Percent)

Years since doctorate	1973	1983	1993	2006
All employed doctorate holders	54.8	48.4	45.9	45.4
≤3	55.2	48.0	50.5	57.3
4–7	55.8	44.9	47.0	51.1
>7	54.2	49.4	45.0	42.9

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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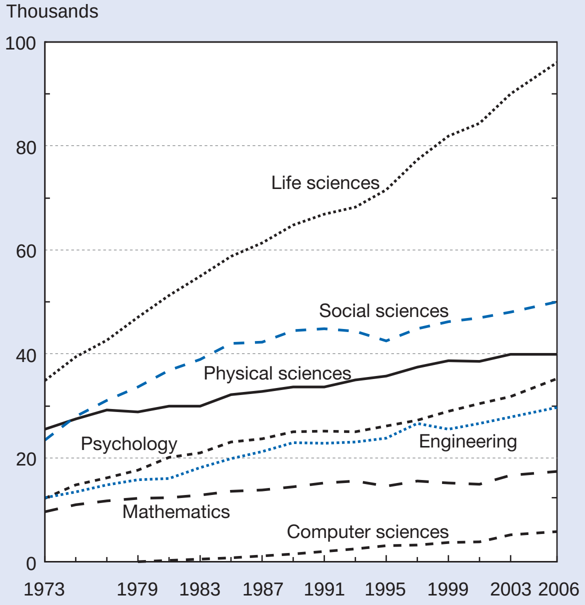
Figure 5-17
S&E doctorate holders employed in academia, by degree field: 1973–2006



NOTES: Physical sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix table 5-17.

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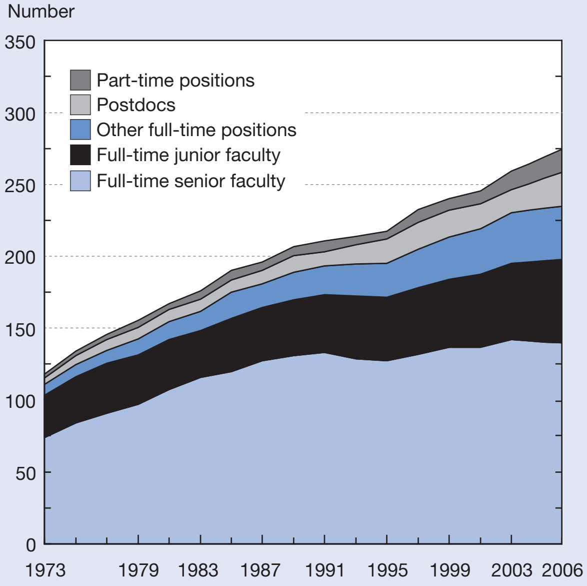
Figure 5-18
S&E doctorate holders, by type of academic appointment: 1973–2006



NOTES: Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors. Other full-time positions include nonfaculty positions such as research associates, adjunct appointments, lecturers, and administrative positions. Part-time employment excludes those employed part time because they are students or retired.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix table 5-17.

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Public universities account for almost two-thirds of S&E doctorate holders employed in academic institutions and an even higher fraction of full-time S&E faculty. Within private research universities, postdocs make up a larger fraction of S&E doctorate holders (22%) than they do within public research universities (12%) (appendix table 5-18).

Women in the Academic Doctoral S&E Workforce

The academic employment of women with S&E doctorates rose sharply between 1973 and 2006, reflecting the increase in the proportion of women among recent S&E doctorate holders. The number of women with S&E doctorates in academia increased more than eightfold during this period, from 10,700 in 1973 to an estimated 90,700 in 2006 (appendix table 5-19), as compared with about a 71% increase for men.

This increase is reflected in the rising share of women among S&E doctorate holders in academic positions. In 2006, women constituted 33% of all academic S&E doctoral employment and 30% of full-time faculty, up from 9% and 7%, respectively, in 1973. Roughly similar percentages of male and female doctoral S&E faculty are employed in re-

Table 5-12

S&E doctorate holders employed in academia, by involvement in research and position: Selected years, 1973–2006

Position/involvement in research	1973	1983	1993	2006
	Thousands			
All academic employment	118.0	176.1	213.8	274.2
Research primary/secondary activity	82.3	104.7	150.1	184.4
	Percent distribution			
All academic employment	100.0	100.0	100.0	100.0
Full-time faculty	87.6	84.3	80.6	72.1
Postdocs	3.5	4.7	6.2	8.5
Other positions	8.9	11.0	13.1	19.4
Research primary/secondary activity	100.0	100.0	100.0	100.0
Full-time faculty	87.5	83.0	81.1	73.4
Postdocs	4.9	7.1	8.9	11.9
Other positions	7.6	9.9	10.0	14.8

NOTES: Research includes basic or applied research, development, and design. Full-time faculty includes full, associate, and assistant professors plus instructors. Other positions include full-time nonfaculty, such as research associates, adjunct positions, lecturers, administrative positions, and part-time positions. Part-time employment excludes those employed part time because they are students or retired. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix tables 5-17 and 5-26.

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search institutions (table 5-13). Compared with male faculty, female faculty remained relatively more heavily concentrated in the life sciences, social sciences, and psychology, with correspondingly lower shares in engineering, the physical sciences, mathematics, and computer sciences.

Women hold a larger share of junior faculty positions than positions at either the associate or full professor rank. However, their share of all three positions rose substantially between 1973 and 2006. In 2006, women constituted 19% of full professors, 34% of associate professors, and 42% of junior faculty, the latter slightly higher than their share of recently earned S&E doctorates (figure 5-19; appendix table 5-19; see also “Doctoral Degrees by Sex” in chapter 2). These trends reflect the recent arrival of significant numbers of women doctorate holders in full-time academic faculty positions. (For a more complete discussion of the role of women, see NSF/SRS 2007c.)

Table 5-13

S&E doctorate holders employed in academia, by sex, race/ethnicity, and Carnegie institution type: 2006

(Percent distribution)

Institution type	All S&E doctorate holders	Female	Male	Asian, non-Hispanic	White, non-Hispanic	Under-represented minority
All institutions	100.0	100.0	100.0	100.0	100.0	100.0
Doctorate-granting universities—very high research activity	42.6	41.9	42.9	51.3	41.8	34.7
Other doctorate-granting institutions	17.6	15.6	18.6	15.9	17.6	20.3
Master’s colleges and universities	17.6	18.0	17.4	12.4	18.2	20.9
Medical schools/medical centers	5.3	6.7	4.7	7.3	5.1	4.6
Baccalaureate colleges	7.7	8.0	7.6	3.2	8.5	8.2
Two-year institutions	3.6	3.8	3.5	1.8	3.8	4.2
Other	5.5	6.0	5.3	8.0	4.9	7.1

NOTES: Institutions designated by 2005 Carnegie classification code. For more information on these institutional categories, see chapter 2 sidebar, “Carnegie Classification of Academic Institutions” and The Carnegie Classification of Institutions of Higher Education, http://www.carnegiefoundation.org/classifications/index.asp, accessed 25 May 2007. Underrepresented minority includes blacks, Hispanics, and American Indians/Alaska Natives.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients 2006, special tabulations (preliminary data).

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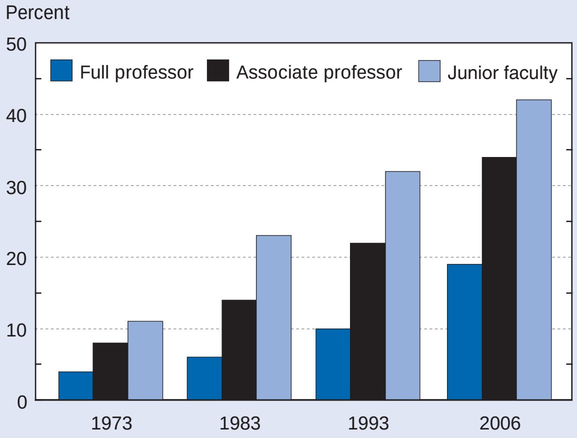
Figure 5-19
Share of doctoral S&E faculty positions held by women, by rank: Selected years, 1973–2006



NOTE: Junior faculty includes assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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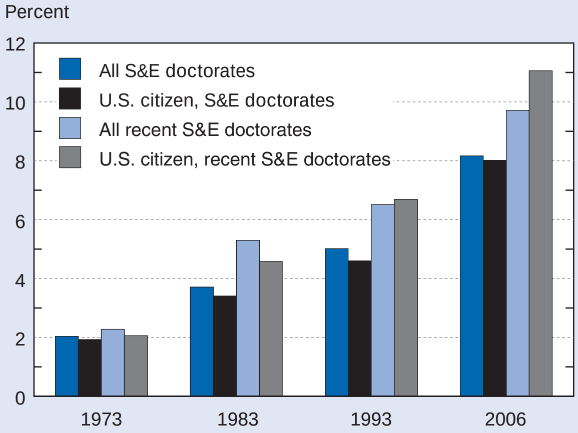
Figure 5-20
Share of underrepresented minorities among S&E doctorate holders employed in academia, by citizenship status and years since degree: Selected years, 1973–2006



NOTES: Underrepresented minorities include blacks, Hispanics, and American Indians/Alaska Natives. Recent doctorate holders earned degrees within 3 years of survey. Denominator always refers to set of individuals defined in legend.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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Underrepresented Minorities in Academic Doctoral Workforce

The Census Bureau's demographic projections have long indicated an increasing prominence of minority groups, especially Hispanics, among future college- and working-age populations. With the exception of Asians/Pacific Islanders, these groups tended to be less likely than whites to earn S&E degrees or work in S&E occupations. Private and governmental groups have sought to broaden the participation of blacks, Hispanics, and American Indians/Alaska Natives in these fields, with many programs targeting their advanced training through the doctorate level.

The absolute rate of conferral of S&E doctorates on members of underrepresented minority groups has increased, as has academic employment; but taken together, blacks, Hispanics, and American Indians/Alaska Natives remain a small percentage of the S&E doctorate holders employed in academia (appendix table 5-20).[26] Because the increases in hiring come from a very small base, these groups constituted only about 8% of both total academic employment and full-time faculty positions in 2006, up from about 2% in 1973. However, among recent doctorate holders, they represented 10% of total academic employment (figure 5-20).

Underrepresented minorities constituted a smaller share of total employment at research universities than at other academic institutions throughout this period (table 5-13). Notably, a lower percentage of black S&E faculty than of other S&E faculty are employed at research universities and a higher percentage are employed at comprehensive universities, especially historically black colleges and universities (NSF/SRS 2006). Underrepresented minorities are concentrated in different fields than whites or Asians. Compared with whites, blacks tended to be relatively concentrated in the social sciences and were relatively less represented in the physical sciences, the life sciences, and engineering. The field distribution of Hispanic degree holders is similar to that of white degree holders. (For a more complete discussion of the role of underrepresented minorities, see NSF/SRS 2007c.)

Asians/Pacific Islanders in Academic Doctoral S&E Workforce

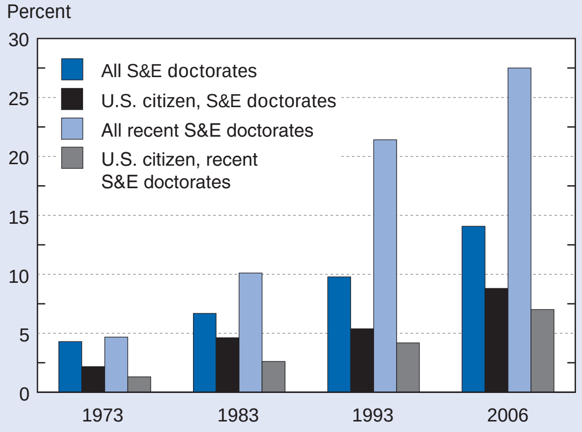
Asians/Pacific Islanders more than tripled their employment share in the S&E academic doctoral workforce between 1973 and 2006, increasing from 4% to 14% (appendix table 5-20). However, a distinction needs to be made between those who are U.S. citizens and those who are not because the latter group constituted 45% of this group's doctorate holders in the academic S&E workforce in 2006.[27] The employment share of Asians/Pacific Islanders who are U.S. citizens grew from about 2% of the total academic S&E doctoral workforce in 1973 to 9% in 2006, a magnitude of growth similar to that of underrepresented minorities. Limiting the analysis to recent S&E doctorate holders leads to even more dramatic differences between Asians/Pacific Islanders who are U.S. citizens and those who are not. Although the Asian/Pacific Islander share of all recent S&E doctorate holders employed in academia rose from 5% in 1973 to 28% in 2006, the share of those who are U.S. citizens increased from 1% to 7% (figure 5-21).

Compared with whites, Asians/Pacific Islanders 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 Asians/Pacific Islanders. In 2006, Asians/Pacific Islanders constituted 29% of academic doctoral computer scientists and 27% of engineers (appendix table 5-20). Whether or not they are U.S. citizens, Asians/Pacific Islanders represent a larger percentage of total employment at research universities than at other academic institutions (table 5-13).

Whites in Academic Doctoral S&E Workforce

The relative prominence of whites, particularly white males, in the academic S&E doctoral workforce diminished between 1973 and 2006 (figure 5-22). In 2006, whites constituted 78% of the academic doctoral S&E workforce, compared with 91% in 1973 (table 5-14; appendix table 5-20); the share of white males also declined during this period, from about 83% to 52%. The decline in the shares of whites and white males who recently received their doctorates was even greater, from 91% to 63% and from 80% to 35%, respectively. Part of the decline is due to the increasing numbers of women, underrepresented minorities, and Asians/Pacific Islanders. However, the decline in share is not the whole story. During the 1990s and through 2006, the absolute number of white males in the academic doctoral S&E workforce who recently received their doctorates remained virtually unchanged.

Figure 5-21
Share of Asians/Pacific Islanders among S&E doctorate holders employed in academia, by citizenship status and years since degree: Selected years, 1973–2006



NOTES: Denominator always refers to set of individuals defined in legend. Recent doctorate holders earned degrees within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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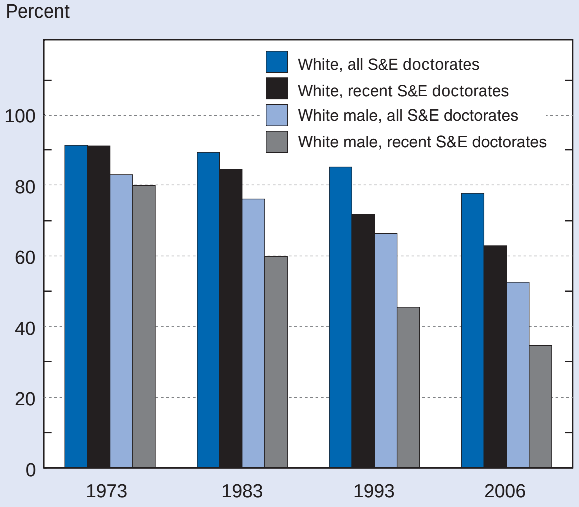
Figure 5-22
Share of all whites and white males among S&E doctorate holders employed in academia, by years since degree: Selected years, 1973–2006



NOTES: Recent doctorate holders earned degrees within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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Foreign-Born S&E Doctorate Holders

Much of the discussion in this chapter is of academic employment of S&E doctorate holders with U.S. doctorates. Because many foreign-born S&E doctorate holders in U.S. academic institutions did not earn their doctorate in the United States, the data in this section are taken from the Department of Education's National Survey of Postsecondary Faculty, which, although it has a smaller sample size and thus less detail by field and other employment characteristics, has information on faculty with non-U.S. doctorates.

Full-time doctoral S&E faculty are increasingly foreign born. In 2003, 28% of all full-time doctoral S&E faculty and 33% of full-time doctoral faculty in research institutions in the United States were foreign born, up from 21% and 25%, respectively, in 1992 (appendix table 5-21). In the physical sciences, mathematics, computer sciences, and engineering, 47% of full-time doctoral S&E faculty in research institutions were foreign born, up from 38% in 1992.

The Aging Professoriate and Trends in Retirement

From 1993 to 2003, retirement rates among doctoral scientists and engineers employed in academic institutions remained relatively stable, despite the application of the Age Discrimination in Employment Act of 1967 to colleges and universities in 1994.[28] The act, which prohibits mandatory retirement on the basis of age, raised questions about the

Table 5-14
White and white male S&E doctorate holders employed in academia, by years since degree: Selected years, 1973–2006

	1973		1983		1993		2006	
Group	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
All S&E doctorate holders	118.0	100	176.3	100	213.8	100	274.2	100
White	107.7	91	157.4	89	181.8	85	213.0	78
Male	97.8	83	134.1	76	141.8	66	143.9	52
Recent S&E doctorate holders	25.0	100	20.5	100	25.1	100	33.9	100
White	22.8	91	17.3	84	18.0	72	21.3	63
Male	20.0	80	12.3	60	11.4	45	11.7	35

NOTES: Recent doctorate holders earned degrees within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006).

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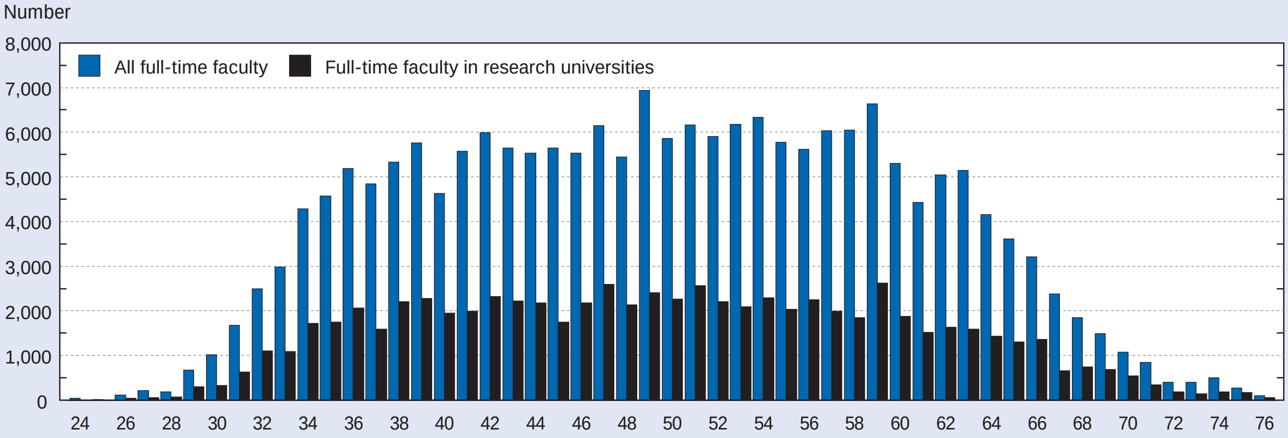
consequences for higher education of an aging professoriate, including fewer academic employment opportunities for new doctorate holders (NRC 1991). Among S&E doctorate holders ages 56–75 whose most recent employment was in the education sector, the percentage who were retired changed little between 1993 and 2003 (NSF/SRS 2008), despite the elimination of mandatory retirement.

Although retirement rates changed little, the age distribution of academic S&E doctorate holders has changed over the past several decades (appendix table 5-22), the percentage of those who are age 65 or older having increased. Full-time S&E faculty employed in research universities account for about 40% of full-time S&E faculty ages 65 and older (figure 5-23). They also have a slightly greater propensity to work longer than faculty in other institutions: 8% of full-time S&E faculty in research universities are ages 65 and older, compared with 6% of those in master's colleges and universities (appendix table 5-23).

Recent S&E Doctorate Holders

Trends in academic employment patterns of those with recently awarded S&E doctorates show a decrease in the share of recent doctorate holders in full-time faculty positions and an increase in postdocs (figure 5-24; appendix table 5-24). Between 1973 and 2006, the share of recent doctorate holders hired into full-time faculty positions fell from 74% to 38%. Conversely, the overall share of recent S&E doctorate holders who reported being in postdoc positions rose from 13% to 46%. After increasing throughout the 1990s, the share of recent S&E doctorate holders in postdoc positions declined from 1999 to 2003 before rising to a new peak in

Figure 5-23
Age distribution of S&E doctorate holders employed in U.S. academic institutions: 2006



NOTES: Research universities are doctorate-granting universities with very high research activity. Institutions designated by 2005 Carnegie classification code. See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," and The Carnegie Classification of Institutions of Higher Education, http://www.carnegiefoundation.org/classifications/index.asp, accessed 25 May 2007.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, 2006, special tabulations (preliminary data).

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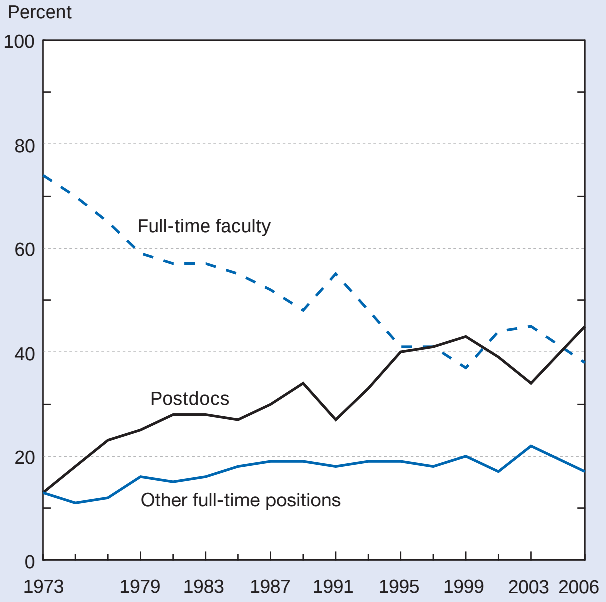
Figure 5-24
S&E doctorate holders with recent degrees employed at academic institutions, by type of position: 1973–2006



NOTES: Recent doctorate holders earned degrees within 3 years of survey. Full-time faculty includes full, associate, and assistant professors plus instructors. Other full-time positions include nonfaculty appointments such as research associates, adjunct appointments, lecturers, and administrative positions. All positions not shown.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix table 5-24.

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2006. Recent S&E doctorate holders who entered academic employment at research universities were more likely to be in postdoc than in faculty positions (appendix table 5-25). (See the discussion of postdocs in chapter 3, "Science and Engineering Labor Force," for more information, including reasons for accepting a postdoc position and short-term career trajectory.)

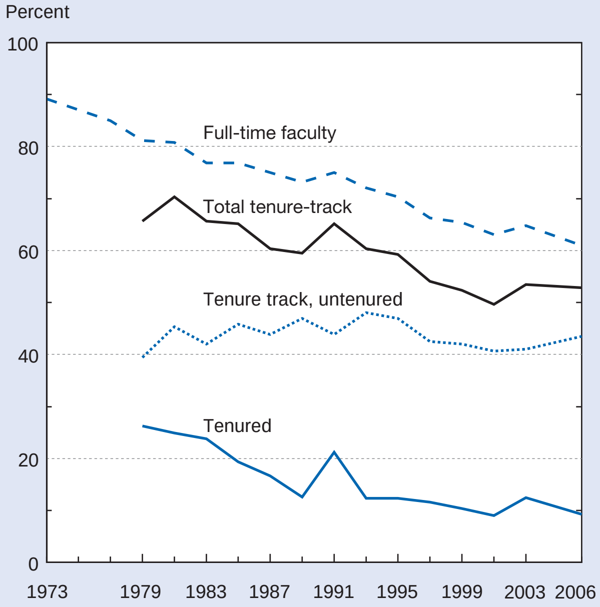
Young Doctorate Holders With a Track Record

For those employed in academia 4–7 years after earning their doctorates, the picture looks quite similar: about 61% had faculty rank in 2006, compared with 89% in 1973 (appendix table 5-24). A little more than half of these doctorate holders were in tenure-track positions in 2006, with about 9% already tenured (figure 5-25).

Academic Researchers

This section examines the number and characteristics of academic S&E doctorate holders for whom research is either a primary or secondary work activity. Note that estimates of the *total* number of academic researchers would include S&E faculty and postdocs as well as research assistants (see chapter 2, appendix tables 2-8 and 2-35) and nondoctoral, nonfaculty research staff. In addition, many other students, both graduate and undergraduate, are also likely to be involved in research activities during the course of their graduate education.

Figure 5-25
Faculty and tenure-track status of S&E doctorate holders employed in academia 4–7 years after receiving degree: 1973–2006



NOTES: Faculty positions include full, associate, and assistant professors and instructors. Tenure-track data not available for 1973–77.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix table 5-24.

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Research as Either Primary or Secondary Work Activity

From 1973 to 2006, the number of academic S&E doctorate holders reporting research as their primary or secondary work activity showed greater growth than the number reporting teaching as their primary or secondary activity. The former group increased from 82,300 in 1973 to 184,400 in 2006, and the latter group increased from 94,900 to 164,000 (appendix table 5-26).[29]

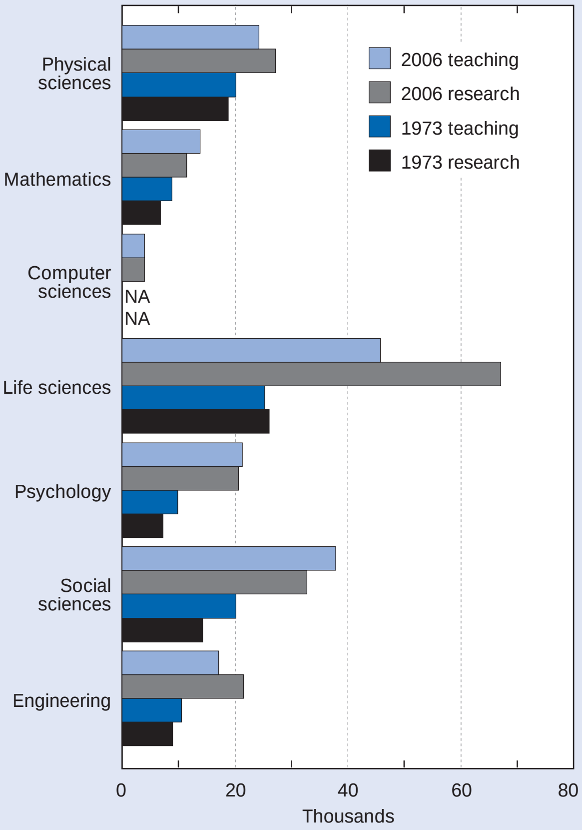
The life sciences accounted for much of this trend, with researchers growing from 26,000 to 67,100 and teachers from about the same base (25,300) to 45,800 (figure 5-26). The other fields generally included fewer researchers than teachers in the 1970s and early 1980s, but this pattern reversed after that time in the physical sciences and engineering.

Relative to all S&E doctoral employment, the number of academic S&E doctorate holders reporting research as either their primary or secondary activity declined between 1973 and 1977; was relatively constant at about 60% from

1977 to 1985, when R&D funds grew relatively slowly; then rose again in 1987 to about 74%, dropped to about 70% in 1993, remained relatively constant at that level until 2003, and dropped slightly in 2006 (appendix tables 5-17 and 5-26). Table 5-15 shows the trends in research involvement by field, and table 5-16 indicates that the distribution across fields of S&E doctorate holders who report research as their primary or secondary work activity is quite similar to that of all S&E doctorate holders.

Research universities employ about 43% of all S&E doctorate holders employed in academic institutions and more than half of those whose primary or secondary work activity is research. They also employ about 76% of S&E postdocs, almost all of whom have research as a primary or secondary work activity (appendix table 5-27).

Figure 5-26
S&E doctorate holders employed in academia with research or teaching as primary or secondary work activity, by degree field: 1973 and 2006



NA = not available

NOTE: Research includes basic or applied research, development, or design. Physical sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, 1973 and 2006, special tabulations (preliminary data for 2006). See appendix table 5-26.

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Time Spent in Research

In 2003, full-time doctoral S&E instructional faculty spent about 27% of their time in research, 52% of their time teaching, and 20% of their time engaged in other activities. The average percentage of time spent in research did not change between 1992 and 2003, but the average percentage of time spent in teaching increased (appendix table 5-28). In 2003, faculty who taught only graduate students spent a higher percentage of their time in research than faculty who taught only undergraduates, and faculty in research institutions spent a higher percentage of their time in research than faculty in nonresearch institutions.

The fraction of full-time doctoral S&E instructional faculty engaged primarily in research increased during the past decade (appendix table 5-29). In 2003, 26% of full-time doctoral S&E instructional faculty were so engaged, compared with 20% in 1992. The fraction engaged primarily in teaching dropped during the past decade, from 61% in 1992 to 53% in 2003. This drop occurred in S&E and non-S&E fields and among doctoral and nondoctoral faculty. Relatively few nondoctoral faculty are engaged in research.

Table 5-15
S&E doctorate holders employed in academia reporting research as primary or secondary activity, by degree field: Selected years, 1973–2006
(Percent)

Degree field	1973	1983	1993	2006
All fields	69.7	59.5	70.2	67.3
Physical sciences	73.7	64.9	71.4	68.1
Mathematics	70.1	55.8	61.3	65.9
Computer sciences	NA	80.0	80.0	69.9
Life sciences	74.5	69.8	76.0	69.8
Psychology	59.8	50.0	59.6	58.3
Social sciences	61.1	45.8	66.0	65.4
Engineering	72.6	61.9	75.8	72.3

NA = not available

NOTES: Research includes basic or applied research, development, and design. Physical sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix tables 5-17 and 5-26.

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Table 5-16

S&E doctorate holders employed in academia reporting research as primary or secondary work activity, by degree field: 2006

(Percent distribution)

Degree field	All academic employment	Research primary/ secondary activity
All fields	100.0	100.0
Physical sciences	14.6	14.7
Mathematics	6.3	6.2
Computer sciences	2.1	2.2
Life sciences	35.1	36.4
Psychology	12.9	11.2
Social sciences	18.2	17.7
Engineering	10.8	20.5

NOTES: Research includes basic or applied research, development, and design. Physical sciences include earth, atmospheric, and ocean sciences. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients 2006, special tabulations (preliminary data). See appendix tables 5-17 and 5-26.

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Government Support of Academic Doctoral Researchers

Academic researchers rely on the federal government for a substantial share (more than 60%) of their overall research support. The institutional and field distributions of these funds are well documented, but little is known about their distribution among 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 5-30 shows the percentage of academic S&E doctorate holders who received federal support for their work during the period 1973–2006, 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.

Academic Scientists and Engineers Who Receive Federal Support

In 2006, 47% of all S&E doctorate holders in academia and 58% of those for whom research was a primary or secondary activity reported federal government support (appendix table 5-30). As table 5-17 shows, for S&E as a whole and for many broad fields, the likelihood of receiving federal support in 2006 was either the same as it was in 1991 or lower.

The percentage of S&E doctorate holders in academia who received federal support differed greatly across the S&E fields. In 2006, this percentage ranged from about 58% in the life sciences and 56% in the physical sciences to 23% in the social sciences (table 5-17; appendix table 5-30).

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, and in 1985, it was to 1 month. However, 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 through 2006 surveys, which again used an entire reference year.

The discussion in this edition of *Indicators* generally compares data for 2006 with data for 1991. 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.

Table 5-17

S&E doctorate holders employed in academia reporting receipt of federal support in previous year, by degree field: Selected years, 1973–2006

(Percent)

Degree field	1973	1983	1991	2006
All fields	44.5	39.8	48.5	46.9
Physical sciences	47.3	46.5	57.0	56.3
Mathematics	26.9	30.1	34.5	34.8
Computer sciences	NA	44.6	49.4	43.9
Life sciences	59.3	60.0	65.5	57.9
Psychology	37.5	30.1	34.7	36.3
Social sciences	25.5	23.7	28.4	23.1
Engineering	53.5	54.7	63.2	58.7

NA = not available

NOTES: 1991 used because 1993 not comparable with other years and understates degree of federal support by asking whether work performed during week of April 15 supported by government. In other years, question pertains to work conducted over course of year. Physical sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix table 5-30.

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Full-time faculty and other full-time doctoral employees received federal support less frequently than postdocs. In 2006, about 46% of full-time faculty, 47% of other full-time employees, and 71% of postdocs received federal support. As indicated earlier, these proportions were lower than those in 1991 but dropped less for full-time faculty than for postdocs or other full-time positions (appendix table 5-30).

NSF and NIH Support for Young Investigators

The share of all NSF grants awarded to new principal investigators (PIs) remained relatively constant from 2002 to 2006, at roughly 27%–28%, while the number of proposal submissions from both new and prior investigators increased and the funding rate both per PI and per proposal decreased. Although the number of new PIs awarded NSF grants remained relatively stable (about 5,300) for the past 5 years, the PI funding rate (based on any award to a PI in a 3-year period) declined, from 30% in 2000–02 to 24% in 2004–06. The number of prior PIs receiving NSF funding also remained relatively stable (about 11,300) for the past 5 years, and the PI funding rate declined, from 54% in 2000–02 to 47% in 2004–06. These success rates based on PIs are somewhat higher than success rates based on proposals, as many investigators submit multiple proposals. When funding rates are calculated based on the number of proposals submitted, the proposal success rate between 2002 and 2006 declines from 19% to 15% for new PIs and from 32% to 26% for prior PIs.

The trend at NIH was similar: the number of new investigators remained stable over time and the funding rate for both new and prior PIs declined in recent years. However, the percentage of all competing Research Project (R01) equivalent awardees who were new awardees declined from 12% in 1980 to 7% in 2005. The average age of new doctoral investigators receiving their first NIH research grant rose from 37 in 1979 to 42 in 2002 (NRC 2005). The proportion of NIH research grant recipients under age 40 dropped from 50% in 1980 to 17% in 2003. Responding to this trend, NIH created the Pathway to Independence award in 2006, which combines funding for up to 2 years of training in a postdoc position and up to 3 years for independent research as a faculty member. The hope is that these awards will be an incentive for universities and colleges to create new positions for these investigators and that the awards will help new investigators win R01 research grants (Kaiser 2006).

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 pattern of support for young researchers is similar to that of the overall academic S&E doctoral workforce. In 2006, S&E doctorate holders with recently earned doctorates (i.e., doctorates earned within 3 years of the survey) who were in full-time faculty positions were less likely to receive federal support than those in postdoc or other full-time positions (appendix table 5-31). For full-time faculty, the percentage reporting federal support in 2006 was lower for those with recently earned doctorates than for the academic S&E doctoral workforce as a whole (appendix tables 5-30 and 5-31). (See sidebar, "NSF and NIH Support for Young Investigators.") It should be pointed out that these data provide no information about whether an individual reporting federal support is being supported as a principal investigator on a research project or is participating in a more dependent status rather than as an independent researcher.

In 2006, about half of those with recently earned doctorates received federal support, with 30% of those in full-time faculty positions, 51% of those in other full-time positions, and 69% of those in postdoc positions (appendix table 5-31). As with all academic doctorate holders, younger researchers were less likely to report federal support in 2006 than in 1991. The share of postdocs with federal support was relatively low (less than 60%) in some fields (e.g., the social sciences and mathematics) and higher in others (e.g., computer sciences, physical sciences, and engineering).

Table 5-18

S&E doctorate holders employed in academia 4–7 years after receiving degree reporting receipt of federal support in previous year, by degree field: Selected years, 1973–2006

(Percent)

Degree field	1973	1983	1991	2006
All fields	47.1	50.1	57.4	47.2
Physical sciences	44.8	66.2	67.2	57.6
Mathematics	29.0	39.8	28.3	32.0
Computer sciences	NA	43.5	66.2	44.8
Life sciences	59.7	67.1	70.6	57.5
Psychology	37.8	32.3	38.8	35.9
Social sciences	29.0	28.1	36.6	21.5
Engineering	50.7	64.3	73.2	63.7

NA = not available

NOTES: 1991 used because 1993 not comparable with other years and understates degree of federal support by asking whether work performed during week of April 15 supported by government. In other years, question pertains to work conducted over course of year. Physical sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations (preliminary data for 2006). See appendix table 5-31.

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Among full-time faculty and postdocs in 2006, those who had received their doctorate 4–7 years earlier were considerably more likely to receive federal support than those with recently earned doctorates. However, those who had received their doctorate 4-7 years earlier were also less likely to receive support in 2006 than in 1991 (table 5-18; appendix table 5-31).

Outputs of S&E Research: Articles and Patents

Chapter 2 of this volume and the previous section of this chapter discuss the outputs of S&E research and education in terms of human capital. This section examines additional indicators of the output of academic S&E research: articles published in the world's S&E literature and patents received by U.S. academic institutions. In addition, licensing activities, royalties, and startups associated with university research are also discussed.

Published, peer-reviewed articles have traditionally been the means by which scientists and engineers report the results of their research and gain status in their fields. According to sociologist Robert K. Merton,

> The institutional conception of science as part of the public domain is linked with the imperative for communication of findings. Secrecy is the antithesis of this norm; full and open communication its enactment. The pressure for diffusion of results is reinforced by the institutional goal of advancing the boundaries of knowledge and by the incentive of recognition which is, of course, contingent upon publication. (Merton, 1973, p. 274; see also de Solla Price 1978)

This section uses data on S&E articles to indicate world S&E knowledge production by country and by selected regions and/or groupings of countries related by geography, cultural ties, language, or political factors. Coauthorship of articles by researchers in different departments, different institutions, and different countries and regions illustrates the increasing trend of collaboration in research, both within and across countries and regions.

Citation of research articles indicates, albeit imperfectly, the relative importance of previously published research findings to future research; consequently, patterns in citation are also discussed in this section. Citation patterns, including trends in highly cited research articles, are contrasted with trends in total publication of articles.

The discussion of research outputs concludes with indicators of the flow of knowledge from academically based research to intellectual capital embodied in patents awarded to academic institutions, along with related other indicators.

S&E Article Output

The number of S&E articles in the dataset analyzed in this chapter totaled 10.6 million for the period 1988–2005.[30] In the past 10 years, the total world S&E article output as contained in the Science Citation Index (SCI) and Social Sciences Citation Index (SSCI) (see sidebar, "Bibliometric Data and Terminology") grew at an average annual rate of 2.3% (table 5-19). This reflects increases in both the number of articles per journal (from 117 in 1988 to 139 in 2005) and the total number of journals (from 4,093 in 1988 to 4,906 in 2005). Scientists and engineers in institutions in the member states of the European Union authored or coauthored one-third of the world total in 2005,[31] followed by the United States with 29% and by 10 Asian countries (hereafter "Asia-10") with 20% (figure 5-27; table 5-19).[32]

Trends in Country and Regional Authorship

Although S&E authors from some 200 countries are represented among the articles discussed in this section, these authors are concentrated in a relatively small number of countries (see sidebar, "Distribution of Publication Data"). Authors from one country, the United States, dominated global article output in 2005 with 29% of the total, followed by Japan with 8% and the United Kingdom, Germany, and China with 6% each.

Previous editions of *Indicators* and other studies (e.g. NSF/SRS 2007a) reported steadily increasing investments in S&E education and research infrastructure, especially in Asia. As these investments matured and led to increased R&D in those countries, authorship by scientists and engineers in those countries also increased, as did their success in getting articles published in international peer-reviewed journals. Differences in recent rates of growth in article production are striking. Among Asian countries/economies that produce a major number of articles (defined here as more than 10,000 articles in 2005), average annual growth rates between 1995 and 2005 were highest in China, at 17%, and South Korea, at 16% (table 5-19). Taiwan's article output grew rapidly as well, at 9% per year. These high rates of growth in S&E article authorship contrast with much slower rates for the world as a whole (2.3%) and for countries with mature S&E infrastructures such as the United States (0.6%) and the countries of the European Union (1.8%). Russia's change in article output was negative over the 10-year period.

The 10-year change rate shown in table 5-19 obscures changes in S&E article output trends that occurred within the period. The growth rate of world output increased from 2.2% on average annually between 1995 and 2000 to 2.4% between 2000 and 2005 (appendix table 5-34). Between 1995 and 2000, U.S. article output was flat at best. This flattening of U.S. article output was the focus of a special NSF study that explored the dimensions of this trend (Bell 2007; Hill et al. 2007; Javitz et al. 2007). Between 2000 and 2005, the U.S. output again turned positive, increasing to an average annual growth rate of 1.3%, more than the 1.1% annual rate of the European Union and less than the 6.3% of the Asia-10 for the same period.

Even among nations with moderate S&E article production (defined as between 1,000 and 10,000 articles in 2005), a few stand out for increasing their publication over the past decade.

Bibliometric Data and Terminology

The article counts, coauthorship data, and citations discussed in this section are derived from S&E articles, notes, and reviews published in a set of the world's most influential scientific and technical journals tracked by Thomson Scientific in the Science Citation Index and Social Sciences Citation Index (http://scientific.thomson.com/products/categories/citation/). The data presented here derive from a database prepared for NSF by ipIQ, Inc., formerly CHI Research, Inc., under a license agreement. The data exclude letters to the editor, news stories, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

These data are not strictly comparable with those presented in editions prior to *Science and Engineering Indicators 2004,* which were based on a fixed SCI/SSCI journal set. The advantage of the "expanding" set of journals is that it better reflects the current mix of journals and articles in the world.

For each new year of data, ipIQ reviews the list of journals and updates the master journal file as necessary as new journals appear and old journals no longer appear or are incorporated into new ones. In other words, the S&E journal literature analyzed for these indicators is always evolving as research and publication evolve. The number of journals analyzed by NSF from SCI/SSCI was 4,093 in 1988 and 4,906 in 2005; over the entire period, some 6,760 journals were reflected in the data. SCI and SSCI give good coverage of a core set of internationally recognized peer-reviewed scientific journals, albeit with some English-language bias. The 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.

Except where noted, *author,* as used here, means *departmental or institutional author.* Articles are attributed to countries or sectors by the country or sector of the institutional address(es) given in the article bylines at the time of publication. If the institutional affiliation is not listed, the article would not be attributed to an institutional author and would not be included in the article counts in this chapter. Likewise, *coauthorship* refers to institutional coauthorship. An article is considered coauthored only if it shows different institutional affiliations or different departments of the same institution. Multiple listings of the same department of an institution are considered as one institutional author. The same logic applies to cross-sector and international collaboration.

Two methods of counting articles based on attribution are used: fractional and whole counts (Gauffriau and Larsen 2005). In *fractional counting,* credit for an article with authors from more than one institution or country is divided among the collaborating institutions or countries based on the proportion of their participating departments or institutions. In *whole counting,* each collaborating institution or country receives one credit for its participation in the article. Fractional counting is generally used for article and citation counts, and whole counting for coauthorship data.

Several changes introduced in this edition of *Indicators* improve the usefulness of the data discussed here but also inhibit comparison with data from the same source used in previous editions.

- Previous editions reported data based on the year an article entered the database ("tape year"), not on the year it was published ("publication year"). In this edition, data in section one *only* ("S&E Article Output") are reported by publication year through 2005 as contained in the 2006 database or tape year. Publication data in the remaining sections ("Coauthorship and Collaboration," "Trends in Output and Collaboration Among U.S. Sectors," and "Trends in Citation of S&E Articles") are reported by tape year as contained in the 2005 database or tape year. Tables and figures refer the reader to which data are reported.
- Breakouts of broad fields of science were adjusted to more closely align with field taxonomies used in other chapters and more commonly recognizable in other NSF/SRS databases and publications. As in previous editions, journals were assigned to 1 of 134 subfields, but these subfields were regrouped into 13 new broad fields (appendix table 5-32). Furthermore, a group of journals in "professional fields" reported on in previous editions has been deleted altogether, resulting in slightly reduced totals overall but a more appropriate concept of science, engineering, or technology journals and articles.
- Finally, the country/economy breakouts were updated to parallel more closely discussions elsewhere in this edition (appendix table 5-33).

Table 5-19
S&E article output, share of world total, and change rate, by major S&E article-producing region/country/economy: 1995–2005

Region/country/economy	1995 Number	1995 Share (%)	2005 Number	2005 Share (%)	Average annual change (%)
World	564,645	100	709,541	100	2.3
United States	193,337	34.2	205,320	28.9	0.6
European Union	195,897	34.7	234,868	33.1	1.8
France	28,847	5.1	30,309	4.3	0.5
Germany	37,645	6.7	44,145	6.2	1.6
Italy	17,880	3.2	24,645	3.5	3.3
Netherlands	12,089	2.1	13,885	2.0	1.4
Spain	11,316	2.0	18,336	2.6	4.9
Sweden	9,287	1.6	10,012	1.4	0.8
United Kingdom	45,498	8.1	45,572	6.4	0.0
Other Western Europe	13,199	2.3	22,333	3.1	5.4
Other former USSR	22,871	4.1	17,822	2.5	-2.5
Russia	18,603	3.3	14,412	2.0	-2.5
Asia-10	76,182	13.5	144,767	20.4	6.6
China	9,061	1.6	41,596	5.9	16.5
India	9,370	1.7	14,608	2.1	4.5
Japan	47,068	8.3	55,471	7.8	1.7
South Korea	3,803	0.7	16,396	2.3	15.7
Taiwan	4,759	0.8	10,841	1.5	8.6
Near East/North Africa	9,476	1.7	13,839	2.0	3.9
Central/South America	9,521	1.7	20,395	2.9	7.9
Other	39,371	7.0	44,826	6.3	1.3
Australia	13,125	2.3	15,957	2.2	2.0
Canada	23,740	4.2	25,836	3.6	0.8

USSR = Union of Soviet Socialist Republics

NOTES: Major S&E article producers = >10,000 articles in 2005. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-33 for all countries/economies included in each region. Detail does not add to total because countries omitted.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-34.

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In the Middle East, Iran's article output grew at 25% a year, although its output was less than 3,000 in 2005 (table 5-20). In Europe, Turkey[33] and Portugal stand out for their rapid growth (16% and 11%, respectively), as do Thailand and Singapore in Asia (14% and 12%, respectively). Brazil stood out in South America with an 11% annual growth rate.

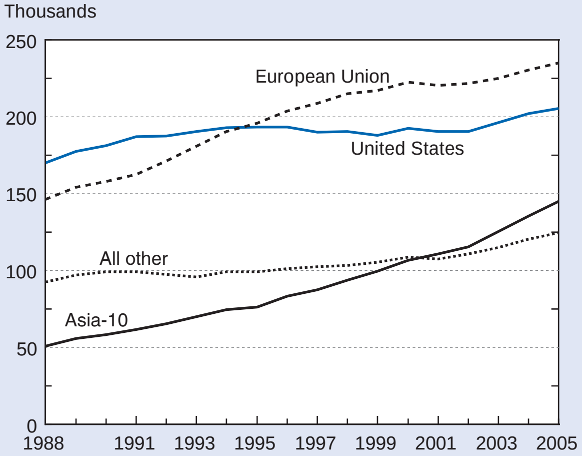
Trends in Country Rank by S&E Field

Figure 5-28 emphasizes that a few countries dominate the world's authorship of S&E articles, and, as noted in the previous discussion, growth rates vary widely across countries. So which countries dominate article authorship by field of S&E, and how are these rankings changing as a result of countries' different rates of growth in publishing?[34]

In a comparison of the top producers of S&E articles in 1995 and 2005, two patterns are evident: (1) U.S. scientists and engineers authored more S&E articles across all fields than authors in any other single country in both 1995 and 2005, and (2) overall, the top 20 article-producing countries were similar in both years (table 5-21). Four countries (the United States, Japan, the United Kingdom, and Germany) were the leading countries across all of S&E in both 1995 and 2005, and their ranks did not change over the period. Three countries among the top 20 producers of S&E articles in 2005 were not in that rank in 1995: South Korea, Brazil, and Turkey. Other notable changes in the ranks of top-producing countries were as follows:

- China's high rates of annual growth in S&E article production resulted in its movement from 14th to 5th place in overall S&E article authorship, to 2nd place in engineering and chemistry, and to 3rd place in physics and mathematics. China moved up in rank of authorships in other fields as well.

Figure 5-27
S&E article output, by major S&E publishing region/country: 1988–2005



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-33 for countries/economies included in each region.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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- South Korea improved its overall rank from 22nd in 1995 to 10th in 2005, with its highest rank (4th) in engineering. It made gains in other fields as well.
- Taiwan moved up in rank overall and in all fields shown except mathematics.
- India failed to demonstrate the fast growth of other Asia-10 countries and lost rank in some fields.
- Brazil and Turkey gained rank across all fields shown.
- Russia, whose growth rate was negative over the period, lost rank across all fields.

Distribution of Publication Data

The publication data used in this section are characterized by many data points, of which only a small number have high value and therefore account for a significant proportion of all the data.* For example, of the 179 countries with a 2005 publication record in the database, 23 accounted for 90% of the 710,000 articles published that year (figure 5-28).

The United States produces 29% of the world total of the articles analyzed in this section, exerting a dominant influence throughout the broad indicators reported here. A middle tier of 12 countries, each of which produces between 2% and 8% of the world total, accounts for another 49% overall. Six countries, each with between 1% and 2% of the world total, account for 8% of the total. The remaining 158 countries together account for the remaining 14% of the world total. Among the lowest tier of countries in terms of total output are countries considered "mature" in S&E, such as Poland, Belgium, Israel, Singapore, and New Zealand.

In each of the sections based on publication records (outputs, international coauthorship, citation rates), an effort was made to limit the amount of data to avoid overwhelming the reader. Data cutoff points are defined where appropriate. The underlying assumption of these cutoffs is that some data may be of interest to a particular country or an academic researcher but not important to the overall world trends. Nevertheless occasional note is made to specific countries in the flat end of the distribution shown in figure 5-28 when needed.

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*Data with these properties belong to a related group of distributions collectively referred to as "power law distributions" (Adamic 2000). Such distributions have traditionally been studied in linguistics, economics, geosciences, and other fields and today commonly appear in studies of the Internet.

Coauthorship and Collaboration

In addition to the increasing volume of the world's S&E published literature discussed in the previous section, another trend was an increase in the number of S&E articles with authors from different institutions. A related and even stronger trend, increases in the number of internationally coauthored S&E articles, was widely noted in previous editions of *Indicators*.[35] The following discussion begins with consideration of broad trends for the world as a whole, moves to regional patterns, and ends with a discussion of country-level trends, including selected country-to-country coauthorship patterns and indexes of international collaboration. (Indicators of cross-sector coauthorship, available only for the United States, are examined below in the section "Trends in Output and Collaboration Among U.S. Sectors.")

Indicators of world S&E article output discussed in the previous section show a growing world article output, with just a few dozen countries producing the predominant proportion of all articles. Within that trend lie three additional patterns of interest: a growing tendency for articles to list multiple authors, authors from more than one institution, and authors from more than one country.

Previous editions of *Indicators* used coauthorship data as an indicator of collaboration among scientists and discussed possible underlying drivers for increased collaboration, including scientific advantages of knowledge and instrument sharing, decreasing costs of travel and communication, national policies, and so forth (NSB 2006). Katz and Martin

Table 5-20
S&E article output, share of world total, and change rate, by medium S&E article-producing country: 1995 and 2005

Country	1995		2005		Average annual change (%)
	Number	Share (%)	Number	Share (%)	
World	564,645	100	709,541	100	2.3
Iran	279	0.1	2,635	0.4	25.2
Turkey	1,715	0.3	7,815	1.1	16.4
Thailand	340	0.1	1,249	0.2	13.9
Singapore	1,141	0.2	3,609	0.5	12.2
Portugal	990	0.2	2,910	0.4	11.4
Brazil	3,436	0.6	9,889	1.4	11.2
Slovenia	434	0.1	1,035	0.1	9.1
Greece	2,058	0.4	4,291	0.6	7.6
Mexico	1,937	0.3	3,902	0.5	7.3
Chile	889	0.2	1,559	0.2	5.8
Ireland	1,218	0.2	2,120	0.3	5.7
Czech Republic	1,955	0.3	3,169	0.4	5.0
Argentina	1,967	0.3	3,058	0.4	4.5
Poland	4,549	0.8	6,844	1.0	4.2
Hungary	1,764	0.3	2,614	0.4	4.0
Austria	3,425	0.6	4,566	0.6	2.9
Belgium	5,172	0.9	6,841	1.0	2.8
Norway	2,920	0.5	3,644	0.5	2.2
New Zealand	2,442	0.4	2,983	0.4	2.0
Switzerland	7,220	1.3	8,749	1.2	1.9
Egypt	1,388	0.2	1,658	0.2	1.8
Finland	4,077	0.7	4,811	0.7	1.7
Denmark	4,330	0.8	5,040	0.7	1.5
Israel	5,741	1.0	6,309	0.9	0.9
South Africa	2,351	0.4	2,392	0.3	0.2
Ukraine	2,516	0.4	2,105	0.3	-1.8

NOTES: Medium S&E article producers = >1,000 and <10,000 articles in 2005. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Detail does not add to total because countries omitted.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-34.

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(1997) and Bordons and Gómez (2000) analyze limitations of coauthorship as an indicator of research collaboration, but other researchers have continued to conduct studies of S&E research collaboration using such data (Adams et al. 2005; Gómez, Fernández, and Sebastián 1999; Lundberg et al. 2006; Wuchty, Jones, and Uzzi 2007; Zitt, Bassecoulard, and Okubo 2000). The coauthorship data used in this section as indicators of collaboration in S&E research are presented with knowledge of neither the motive(s) underlying the collaboration nor the nature of the collaboration that actually occurred.[36] They should be seen as broad indicators of a secular trend in the S&E publishing record that reflects changes in the way S&E research is conducted and reported in today's world.

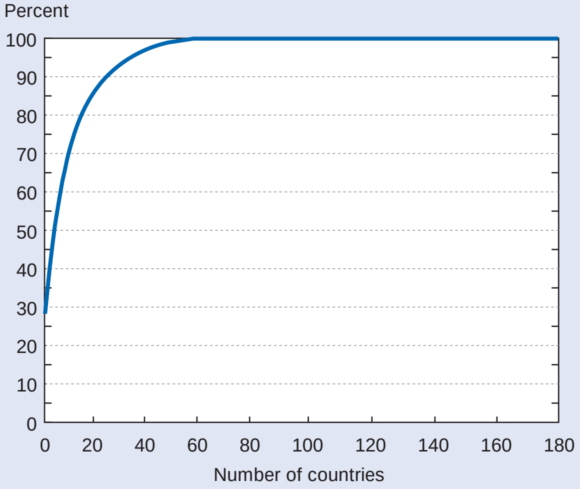
Article Author Names and Institutions

Indicators of the extent of these changes are shown in figure 5-29, which depicts the annual number of S&E articles published worldwide relative to the number of author names[37] and different institutions that appear in article bylines. Between 1988 and 2005, the number of S&E articles, notes, and reviews grew by 60% and both the number of institutions and the number of author names more than doubled. The number of author names per article for S&E overall increased from 3.1 in 1988 to 4.5 in 2005, and this growth occurred in all of the broad S&E fields (table 5-22). Growth on this indicator was slower in mathematics and the social sciences, and more rapid in physics and the medical sciences.

A slightly different indicator, coauthored articles, has also increased steadily. *Coauthored articles* are defined as S&E articles with more than one institutional address in the byline. ("Institution" here may refer to different departments or units within the same institution; multiple listings of the same department or unit are counted as one institutional author.) Adams and colleagues (2005) offer several hypotheses that might explain growing collaboration, including special-

Figure 5-28

Worldwide output of S&E articles, by number of article-producing countries: 2005



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-34.

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ization by researchers and a consequent increase in division of labor; decreases over time in the cost of collaboration (and of international collaboration) due to the Internet; and increases in the sharing of large research resources like instruments and large datasets. They also argue that increases in the division of labor of scientists on a team lead to increases in scientific productivity. On the other hand, Cummings and Kiesler (2005, 2007) report high coordination costs in studies of two large U.S. government programs that sought to foster collaboration.

Coauthored articles grew from 40% of the world's S&E articles in 1988 to 61% in 2005 (figure 5-30). This growth has two parts: (1) coauthored articles that list only domestic institutions in the byline, and (2) articles that list institutions from more than one country, that is, internationally coauthored articles, which may also have multiple domestic institutional authors as well. The remainder of this section focuses on these internationally coauthored articles.

Coauthorship From a Regional Perspective

Use of the same region/country categories as in "S&E Article Output" above shows changes in the patterns of interregional coauthorship.[38] Over the period 1995–2005, interregional coauthorship increased as a percentage of total article output for the United States (from 17% to 27%), the European Union (from 18% to 26%), and the Asia-10 (from

Table 5-21

Rank in S&E article output, by country/economy and selected S&E broad field: 1995 and 2005

	All fields		Engineering		Chemistry		Physics		Geosciences		Mathematics		Biological sciences		Medical sciences	
Country/economy	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005
U.S.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Japan	2	2	2	3	2	3	2	2	5	3	8	7	3	2	3	3
UK	3	3	3	5	6	8	6	7	2	2	4	5	2	3	2	2
Germany	4	4	4	6	3	4	3	4	6	5	3	4	4	4	4	4
China	14	5	8	2	11	2	7	3	15	7	9	3	20	7	21	11
France	5	6	6	7	5	6	5	5	4	6	2	2	5	5	5	7
Canada	6	7	5	8	10	12	9	12	3	4	5	10	6	6	7	6
Italy	8	8	10	10	8	10	8	8	9	9	6	6	7	8	6	5
Spain	11	9	15	12	9	9	11	11	11	10	10	8	11	9	11	10
South Korea	22	10	13	4	15	11	15	9	35	19	24	12	29	13	31	14
Australia	9	11	12	14	14	17	17	18	7	8	11	13	8	10	9	9
India	12	12	9	11	7	7	10	10	13	12	17	21	14	12	19	20
Russia	7	13	7	13	4	5	4	6	8	11	7	9	9	18	22	28
Netherlands	10	14	14	18	13	16	14	17	10	13	13	16	10	11	8	8
Taiwan	18	15	11	9	17	14	20	13	23	15	20	20	22	19	20	16
Sweden	13	16	16	19	18	21	18	19	12	18	15	18	12	14	10	12
Brazil	23	17	25	16	25	15	21	15	24	16	19	15	19	15	24	17
Switzerland	15	18	19	21	16	18	13	16	16	14	16	19	13	16	12	15
Turkey	34	19	26	17	29	20	37	25	29	21	44	27	34	24	25	13
Poland	19	20	18	20	12	13	12	14	27	29	14	14	25	23	28	26

UK = United Kingdom

NOTES: Countries initially ranked on 2005 total article output. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. China includes Hong Kong.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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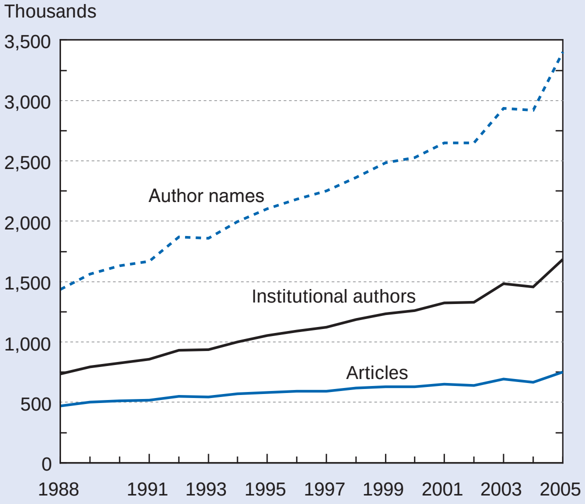
Figure 5-29
Worldwide S&E articles, institutional authors, and author names: 1988–2005



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication. Author name counted each time it appears in data set. Authors assigned to institution on basis of institutional address listed on article; authors from separate departments each counted as individual institutional author; multiple authors from same department of institution considered as one institutional author.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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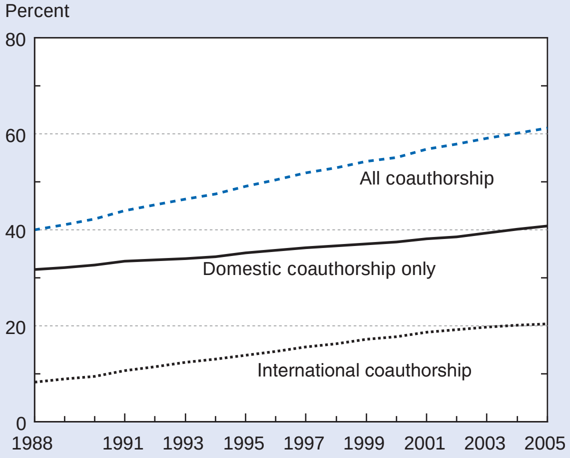
Figure 5-30
Share of worldwide S&E articles coauthored domestically and internationally: 1988–2005



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating institution or country credited one count. Internationally coauthored articles may also have multiple domestic coauthors.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Table 5-22
Authors per S&E article, by field: 1988 and 2005

Field	1988	2005
All fields	3.1	4.5
Engineering	2.5	3.6
Astronomy	2.5	5.0
Chemistry	3.1	4.1
Physics	3.3	5.4
Geosciences	2.4	3.7
Mathematics	1.5	1.9
Computer sciences	1.9	2.8
Agricultural sciences	2.7	4.0
Biological sciences	3.3	4.9
Medical sciences	3.6	5.3
Other life sciences	2.0	3.1
Psychology	2.1	2.9
Social sciences	1.4	1.8

NOTE: Articles classified by year they entered database rather than year of publication.

SOURCES: Thomson Scientific, Science Citation Index and Social Sciences Citation Index, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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16% to 19%) (table 5-23). As a percentage of the world's interregionally coauthored articles, the shares of articles with a U.S. or European Union institutional author declined slightly, giving way to a rise in the share of articles with an institutional author from the Asia-10 (from 22% in 1995 to 28% in 2005). The other regions identified in table 5-23 tend to have a less-developed S&E infrastructure, and scientists and engineers in those regions tend more often to coauthor articles with colleagues in the more scientifically advanced regions/countries. For example, 41% of all S&E articles with an institutional author from the Near East/North Africa (which includes Israel) had an author from another region, as did 59% of S&E articles with an institutional author from Sub-Saharan Africa (which includes South Africa). The following sections look more closely at coauthorship patterns of specific countries and country pairs.

Coauthorship Patterns From an International Perspective

When the region-level data discussed in the previous section are disaggregated to the country level, a richer picture of international S&E article coauthorship emerges. Table 5-24 displays the international coauthorship rates of countries that had institutional authors on at least 1% or more of

Table 5-23
Interregional collaboration on S&E articles: 1995 and 2005
(Percent)

Region/country	Share region's/country's total article output 1995	Share region's/country's total article output 2005	Share world's interregional articles 1995	Share world's interregional articles 2005
United States	17	27	60	57
European Union	18	26	66	65
Other Western Europe	41	44	12	12
Asia-10	16	19	22	28
Other Asia	51	66	1	1
Other former USSR	22	42	10	9
Near East/North Africa	36	41	7	7
Central/South America	39	40	8	9
Sub-Saharan Africa	41	59	4	3
Other	27	40	20	21

USSR = Union of Soviet Socialist Republics

NOTES: Interregionally coauthored articles have at least one collaborating institution from indicated region/country and an institution from outside that region/country. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. See appendix table 5-33 for countries/economies included in each region. Detail adds to >100% because articles may have authors from more than two countries/economies.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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the world's internationally coauthored S&E articles in 2005. The sheer number of U.S. coauthored articles dominates these measures, accounting for 44% of the world total. As discussed in the sidebar "Distribution of Publication Data," a relatively small number of countries account for a large proportion of the world's internationally coauthored articles. But a country's number of internationally coauthored articles (i.e., its "size") is not a reliable predictor of the propensity of that country's scientists to engage in international coauthorship (Narin, Stevens, and Whitlow 1991). Countries of very different article output volumes (e.g., the United Kingdom with 28,000 internationally coauthored articles and Finland with 3,400) show similar rates of international coauthorship (44% and 48%, respectively). In contrast, the number of Japan's internationally coauthored articles is similar to Italy's, but Japan's international coauthorship rate (23%) is well below Italy's (43%).

Narin and colleagues (1991) concluded that "the direction of international coauthorship is heavily dependent on linguistic and historical factors." Coauthorship data suggest intriguing "preferences" at the national level (Glänzel and Schubert 2005; Schubert and Glänzel 2006) based on the geography, cultural relations, and language of particular pairs or sets of countries, and these preferences have been evolving over time (Glänzel 2001). Some researchers have focused on the growing S&E article output and international coauthorship of particular countries mentioned in the previous section, for example, Korea (Kim 2005), China (Zhou and Leydesdorff 2006), and Turkey (Uzun 2006).

International Coauthorship With the United States

When authors of S&E articles from U.S. institutions collaborate with authors from abroad, in which countries are these authors likely to be located? Table 5-25 lists the 30 countries whose institutions appeared on at least 1% or more of U.S. internationally coauthored articles in 2005. U.S. authors are most likely to coauthor with colleagues from Germany (13.5%), the United Kingdom (13.4%), and Canada (11.9%).

Readers may note the asymmetry between the columns of data in table 5-25: each country's share of coauthorship in U.S. internationally coauthored articles is lower than the U.S. share of that country's international articles.[39] To some extent, the asymmetry may simply reflect the dominating effect of the size of U.S. S&E across the globe, including the number of publishing scientists and engineers (see sidebar, "Distribution of Publication Data"). For example, scientists and engineers from Canada may relatively more often collaborate with scientists and engineers in the United States (52%) than the reverse (12%) simply because there are more scientists and engineers in the United States than in Canada.[40] Canada and the United States are also close geographically and linguistically, and these factors may reinforce the size effect of the United States. Likewise, the difference in the rates of coauthorship between the United States and Israel (53% for Israel with the United States versus 3% for the United States with Israel) may reflect historical and ethnic factors in addition to the size effect of the United States. The discussion in the next section shows how removing the effect of size identifies specific country pairs of strong coauthorship across the world.

International Collaboration in S&E

In developing indicators of international collaboration between countries and across regions, researchers have developed statistical techniques that account for unequal sizes in countries' S&E article output and coauthorship patterns (Glänzel and Schubert 2004). One of the simplest of these techniques is used in calculating the *index of international collaboration* shown in table 5-26. A country-to-country index is calculated by dividing a country's rate of collaboration with another country by the other country's rate of international coauthorship (Narin, Stevens, and Whitlow 1991). For example, if 12% of country A's coauthored ar-

Table 5-24

International collaboration on S&E articles, by selected region/country/economy: 2005

(Percent)

Region/country/economy	Share country's/economy's total article output	Share world's internationally coauthored articles
United States	27	44
European Union		
Austria	57	3
Belgium	58	4
Czech Republic	52	2
Denmark	54	3
Finland	48	2
France	49	14
Germany	47	20
Greece	40	2
Hungary	56	2
Ireland	52	1
Italy	43	9
Netherlands	49	7
Poland	47	3
Portugal	54	2
Spain	42	7
Sweden	50	5
United Kingdom	44	19
Other Western Europe		
Norway	52	2
Switzerland	59	6
Turkey	19	1
Asia-10		
China	25	8
India	22	3
Japan	23	10
Singapore	41	1
South Korea	28	4
Taiwan	21	2
Other former USSR		
Russia	43	6
Ukraine	52	1
Near East/North Africa		
Israel	44	3
Central/South America		
Argentina	47	1
Brazil	35	3
Mexico	46	2
Sub-Saharan Africa		
South Africa	49	1
Other		
Australia	41	6
Canada	43	10
New Zealand	48	1

USSR = Union of Soviet Socialist Republics

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. Countries with <1% of international total omitted. See appendix table 5-33 for all countries/economies included in each region. Detail adds to >100% because articles may have authors from more than two countries/economies.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-35.

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Table 5-25

International coauthorship of S&E articles with the United States, by selected country/economy: 2005

(Percent)

Country/economy	U.S. share of country's/ economy's international articles	Country's/ economy's share of U.S.'s international articles
Germany	30.1	13.5
United Kingdom	31.5	13.4
Canada	52.1	11.9
Japan	39.8	9.1
France	25.7	8.5
China	39.9	7.5
Italy	33.0	7.2
Australia	35.2	4.8
South Korea	54.7	4.6
Netherlands	30.4	4.6
Spain	26.6	4.2
Switzerland	30.6	4.0
Russia	27.6	3.5
Sweden	27.8	3.2
Israel	52.5	3.0
Brazil	38.9	2.6
Belgium	23.0	2.2
Taiwan	55.5	2.2
India	36.2	2.1
Poland	27.0	1.9
Denmark	28.2	1.8
Mexico	42.8	1.6
Austria	23.3	1.5
Finland	26.7	1.4
Norway	30.8	1.3
Turkey	44.8	1.2
Greece	32.9	1.1
Argentina	33.8	1.0
New Zealand	32.8	1.0
Hungary	27.9	1.0

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-35.

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Table 5-26

International collaboration on S&E articles, by selected region and country/economy pair: 2005

Region, country/economy pair	International collaboration index
North/South America	
Canada–U.S.	1.19
Mexico–U.S.	0.98
U.S.–Brazil	0.89
Argentina–Brazil	5.01
Mexico–Argentina	3.06
North Atlantic	
UK–U.S.	0.72
Germany–U.S.	0.69
France–U.S.	0.59
Canada–UK	0.72
Canada–France	0.66
Europe	
France–Germany	0.86
France–UK	0.83
Germany–UK	0.79
Spain–France	1.27
Italy–Switzerland	1.39
Norway–Denmark	4.64
Finland–Sweden	3.84
Sweden–Denmark	3.48
Pacific Rim	
Japan–U.S.	0.91
China–U.S.	0.91
South Korea–U.S.	1.25
Taiwan–U.S.	1.27
China–Canada	0.74
Japan–Canada	0.52
Asia/South Pacific	
China–Japan	1.56
South Korea–Japan	2.02
Australia–Singapore	1.72
Australia–China	1.07
Australia–New Zealand	4.23
India–Japan	1.31
India–South Korea	1.84

UK = United Kingdom

NOTES: International collaboration index is first country's rate of collaboration with second country divided by second country's rate of international coauthorship. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-35.

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ticles are with country B, and country B produces 12% of internationally coauthored articles, the expected country-to-country collaboration index is 1 (12%/12%). Indexes greater than 1 represent greater than expected rates of coauthorship, and indexes less than 1 represent less than expected rates of coauthorship.

Table 5-26 lists the international collaboration index for selected pairs of countries. The indexes for all pairs of countries that produced at least 1% of all internationally coauthored articles in 2005 can be calculated from the data in appendix table 5-35. In North America, the Canada-United States index of 1.19 shows a rate of collaboration that is slightly greater than would be expected based solely on the number of internationally coauthored articles produced by each of these two countries. The United States-Mexico index of 0.98 is just about as would be predicted, whereas Mexico's collaboration with Argentina is much stronger than expected, at 3.06. In South America, the collaboration index of Argentina-Brazil, at 5.01, is one of the highest in the world.

None of the collaboration indexes between countries on opposite sides of the North Atlantic was as high as expected based on their total international collaboration. In Europe, collaboration patterns were mixed. Among the large publishing countries of Germany, the United Kingdom, and France, collaboration was less than expected. The indexes for France-Spain and Italy-Switzerland were somewhat higher than expected, and very strong rates of collaboration were evident throughout Scandinavia.

Cross-Pacific collaboration was rather weak between the United States and both China and Japan, but somewhat stronger than expected between the United States and both South Korea and Taiwan. Canada showed a lower tendency than the United States to coauthor with other Pacific Rim countries.

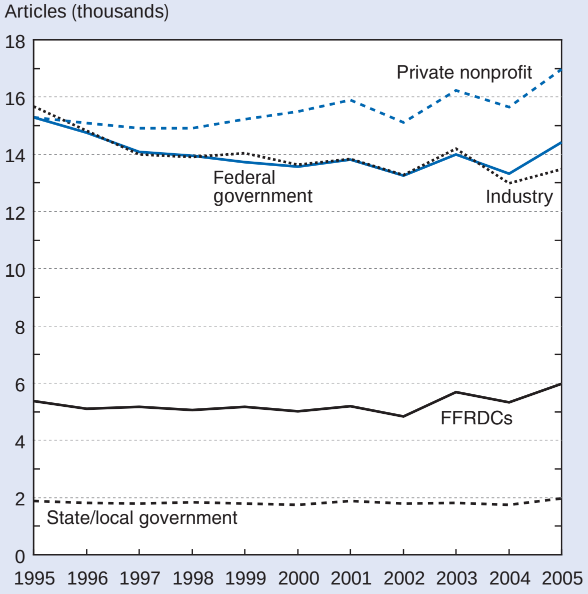
Collaboration indexes between the large article producers within the Asia-10 were generally higher than expected. Indexes for Japan-China and for Japan-South Korea were strong. Australia's collaboration with Singapore (1.72) and New Zealand (4.23) was particularly strong. India collaborated more than would be expected with Japan (1.31) and South Korea (1.84).

Trends in Output and Collaboration Among U.S. Sectors

S&E articles authored at academic institutions have traditionally accounted for just under three-fourths of all U.S. articles (appendix table 5-36). This section takes a closer look at nonacademic authorship, including output trends by sector and the extent of coauthorship, both between U.S. sectors and between U.S. sectors and authors abroad. (For a more detailed discussion of industry authorship, see "Industry Collaboration in Publications" in chapter 6.)

Figure 5-31

S&E article output of U.S. nonacademic sectors: 1995–2005



FFRDC = federally funded research and development center

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on basis of proportion of its participating institutions. Joint and unknown sectors omitted.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-36.

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Article Output by Sector

Total annual publications by authors in U.S. nonacademic sectors changed little over the past decade (appendix table 5-36). Authorship by scientists and engineers in the federal government and in industry declined overall (figure 5-31). Articles with nonprofit institutional authors have trended upward, primarily due to increases in the medical sciences. State and local government authorship, dominated by articles in the medical and biological sciences, remained constant across the decade. The article output of federally funded research and development centers (FFRDCs) remained flat until 2002 but has recently shown increases. (See sidebar "S&E Articles From Federally Funded Research and Development Centers.")

Trends in Sector Coauthorship

The previous section on "Coauthorship and Collaboration" presented coauthorship data as an indicator of collaboration between and among U.S. and foreign scientists and engineers. This section considers coauthorship data as an indicator of collaboration at the sectoral level between U.S.

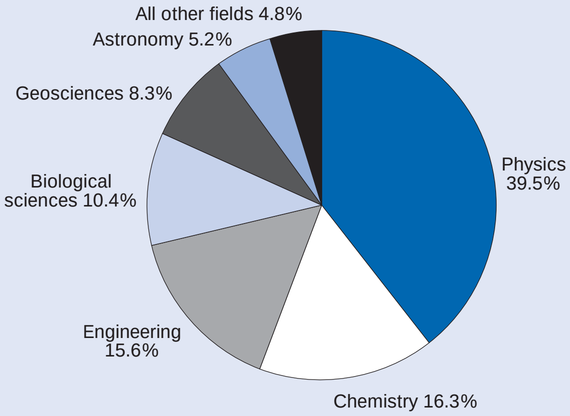
S&E Articles From Federally Funded Research and Development Centers

FFRDCs are research offices/laboratories sponsored by federal agencies and administered by universities, industry, or other nonprofit institutions. FFRDCs have specialized research agendas closely related to the mission of the sponsoring agency and may house large and unique research instruments not otherwise available in other research venues.

Although all of the broad fields of science considered in this chapter contain articles authored at FFRDCs, a handful of these fields dominates publication by this sector and points to their specialized research programs. Physics articles account for 40% of the FFRDC total (figure 5-32) but only 10% of the academic sector total (appendix table 5-36). Chemistry and engineering articles each account for another 16% of the FFRDC total.

Nine federal agencies (the Departments of Defense, Energy, Health and Human Services, Homeland Security, Transportation, and Treasury, the National Aeronautics and Space Administration, the Nuclear Regulatory Commission, and the National Science Foundation) sponsor some three dozen FFRDCs (NSF/SRS, 2007b), but the 16 centers sponsored by the Department of Energy dominate S&E publishing by this sector. Across all fields of S&E, DOE-sponsored labs accounted for 83% of the total for the sector in 2005. Scientists and engineers at DOE-sponsored FFRDCs published 96% of the sector's articles in chemistry, 95% in physics, and 90% in engineering (NSF, special tabulations).

Figure 5-32
S&E articles from FFRDCs, by field: 2005



FFRDC = federally funded research and development center

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on basis of proportion of its participating institutions. Detail does not add to total because of rounding.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-36.

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institutional authors and between U.S. sectors and foreign institutions.[41] These data show that the growing integration of R&D activities, as measured by coauthorship, is occurring across the full range of R&D-performing institutions.

Between 1995 and 2005, coauthorship increased in all U.S. sectors and, most notably, between U.S. institutional authors in all sectors and non-U.S. authors. Authors in FFRDCs, industry, and private nonprofit institutions increased their coauthorship with foreign authors by 10 percentage points between 1995 and 2005 (table 5-27). Authors at FFRDCs reached the highest rate of collaboration with foreign authors, at 38%, followed by industry at 26%. Coauthorship with foreign authors increased by 9 percentage points for authors in the federal government and academia and by 5.5 percentage points for authors in state/local government.

The extent of coauthorship between U.S. sectors and authors from another country varied by broad field of science. Astronomy had the highest rate of international coauthorship in 2005, at 58%, well above the U.S. national average of 27% across all fields and all sectors (appendix table 5-37). Within astronomy, authors at FFRDCs, in the federal government, in academia, and in private nonprofit institutions increased their international coauthorship over the decade 1995–2005 at some of the highest rates compared with other S&E fields. The geosciences, mathematics, and physics also experienced higher than average growth in international coauthorship in most sectors.

U.S. cross-sectoral coauthorship increased between all sectors except FFRDCs and industry. The largest gains in all sectors were with coauthors in academia (by far the largest sector with the largest pool of potential S&E coauthors). State/local government, the sector with the highest percentage of articles with coauthors from academia in 1995, at 63%, also had the highest percentage in 2005, at 71%, followed by private nonprofit institutions at 62% and the federal government at 59% (table 5-27).

Within-sector coauthorship (e.g., FFRDC authors with authors from other FFRDCs) increased as well.[42] Starting from the highest base of within-sector coauthorship in 1995, at 36%, academic authors increased their coauthorship with authors from other academic institutions to 43% in 2005. FFRDC-FFRDC coauthorship, and private nonprofit/private nonprofit coauthorship both increased by more than 4 percentage points over the decade.

Except for the decline in coauthorship between FFRDCs and industry, the indicators presented in this section show steadily increasing integration between and among the different types of U.S. institutions that publish the results of

Table 5-27

U.S. article coauthorship, by sector, foreign coauthorship, and U.S. coauthor sector: 1995 and 2005

(Percent)

		U.S. coauthor sector					
Year/sector	Foreign coauthor	FFRDCs	Federal government	State/local government	Academic institutions	Industry	Private nonprofit
1995							
FFRDCs	28.2	12.7	7.1	0.2	44.5	8.7	3.3
Federal government	16.2	2.5	16.9	1.9	51.3	8.5	7.6
State/local government	9.9	0.6	13.5	12.8	63.2	8.0	15.3
Academic institutions	16.6	2.4	7.7	1.4	36.3	5.7	8.4
Industry	16.1	3.3	9.1	1.2	40.3	13.7	7.2
Private nonprofit	14.4	1.2	7.6	2.2	56.1	6.8	22.9
2005							
FFRDCs	38.3	16.9	8.2	0.3	54.3	6.9	4.2
Federal government	25.2	3.4	19.3	2.7	58.8	9.3	11.1
State/local government	15.3	0.8	16.9	15.6	70.6	10.3	19.3
Academic institutions	25.6	3.1	8.0	1.5	42.9	6.1	9.7
Industry	26.3	3.2	10.5	1.8	50.7	16.0	11.8
Private nonprofit	24.4	1.5	9.6	2.6	61.8	9.1	27.4
1995–2005 change (percentage points)							
FFRDCs	10.1	4.2	1.1	0.1	9.8	-1.8	0.9
Federal government	9.1	0.9	2.4	0.8	7.5	0.8	3.5
State/local government	5.5	0.2	3.4	2.8	7.5	2.3	4.0
Academic institutions	9.0	0.7	0.3	0.2	6.6	0.4	1.3
Industry	10.2	-0.1	1.4	0.6	10.3	2.3	4.6
Private nonprofit	10.0	0.3	2.0	0.5	5.6	2.3	4.6

FFRDC = federally funded research and development center

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered the database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country or sector credited one count. Articles from joint or unknown sectors omitted. Detail may add to >100% because articles may have authors from more than two sectors.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-37.

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R&D in the scientific and technical literature. The data in table 5-27 indicate that more of these coauthors have been from another department within an institution,[43] from another institution within the same sector, or from an institution in another sector. Growth in coauthorship has been particularly strong between U.S. authors in all sectors and authors in foreign institutions.

Trends in Citation of S&E Articles

When scientists and engineers cite the published results of previous research, they are formally crediting the influence of that research on their own work. Previous editions of *Indicators* presented data on the growing number of worldwide citations to foreign S&E literature. Like the indicators of international coauthorship discussed above, cross-national citations are evidence that S&E research is increasingly international in scope.

The indicators discussed here present a coherent picture of a world S&E literature dominated by the United States. At the same time, a decade of increases in the publication of research articles by a few dozen countries in Asia and Europe has chipped away at the U.S. share on a number of publication indicators. The following sections continue to explore this theme by contrasting worldwide research output trends with worldwide trends in highly cited S&E literature by field.

Citation Trends in a Global Context

Much of the world's S&E research literature is never cited in another article, although citation rates vary by field (appendix table 5-38).[44] Concomitant with changing shares of the world total of S&E research articles, shares of the world total of citations to these articles have also been changing. Appendix table 5-38 shows, for example, that between 1991–93 and 2001–03, the U.S. world share of S&E articles declined from 36% to 30%, while the European Union share grew from 33% to 35% and the Asia-10 share grew from 13% to 18%. Table 5-28 provides the parallel percentages for share of citations, showing a largely similar pattern: a decline for the United States from 50% to 41%, an increase for the European Union from 31% to 34%, and an increase for the Asia-10 from 8% to 13%. Figure 5-33 illustrates these changes. Other regions of the world remained relatively unchanged on these indicators during the period.

Trends in Highly Cited S&E Literature

Another indicator of performance of a national or regional S&E system is the share of its articles that are highly cited. High citation rates can indicate that an article has a greater impact on subsequent research than articles with lower citation rates.

Citation percentiles for 1995, 2000, and 2005 are shown by field and region/country in appendix table 5-38.[45] In appendix table 5-38, a region/country whose research influence is disproportionate to its output would have higher numbers of articles at higher citation percentiles, whereas a country whose influence was less than its output would suggest would have higher numbers of articles at lower citation percentiles. In other words, a country whose research has high influence would have higher shares of its articles in higher citation percentiles.

This is the case in every field for U.S. articles. Across the 11 years displayed in appendix table 5-38, the U.S. share of articles in the 99th percentile was higher than its share in the 95th percentile, and these were higher than its share in the 90th percentile, and so forth, even while the U.S. share of all articles was decreasing. In contrast, in every field shown in appendix table 5-38, the shares of European Union and Asia-10 articles in each percentile were inversely proportional to the citation percentiles, even as their share of all articles was increasing. Figure 5-34 displays these relationships for the United States, European Union, and Asia-10; only U.S. publications display the ideal relationship of consistently higher proportions of articles in the higher percentiles of article citations across the period.

These data are summarized in appendix table 5-39, which focuses only on the 99th percentile of article citations. As the U.S. share of all articles produced declined between 1995 and 2005, its share of articles in the 99th percentile (i.e., the top 1%) of cited articles also declined, particularly in some fields. The share of articles produced by the European Union and the Asia-10 increased over the same period, as did their shares of articles in the 99th percentile of cited articles.

However, when citation rates are normalized by the share of articles during the citation period to produce an index of highly cited articles, the influence of U.S. articles is shown to increase. Between 1995 and 2005, the U.S. index of highly cited articles increased from 1.73 to 1.83 (figure 5-35). During the same period, the European Union's index increased from 0.75 to 0.84 and the Asia-10's increased from 0.39 to

Table 5-28
Share of world citations of S&E articles, by major region/country: 1995, 2000, and 2005
(Percent)

Region/country	1995	2000	2005
United States	49.6	44.8	40.8
European Union	30.6	33.3	33.7
Other Western Europe	2.3	2.5	2.5
Asia-10	8.2	9.8	12.9
Other Asia	0.0	0.0	0.1
Other former USSR	1.0	1.0	0.8
Near East/North Africa	1.0	1.1	1.2
Central/South America	0.7	1.0	1.5
Sub-Saharan Africa	0.3	0.3	0.3
Other	6.3	6.3	6.1

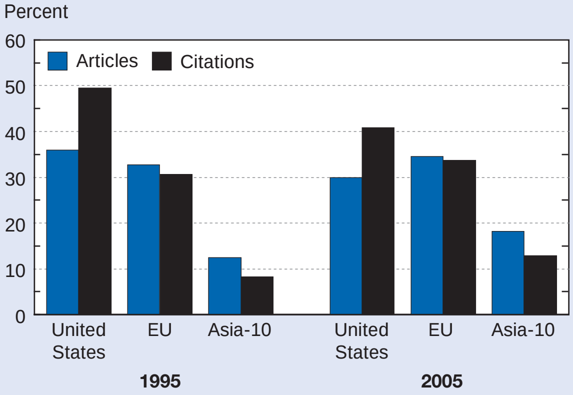
USSR = Union of Soviet Socialist Republics

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Citation counts based on 3-year period with 2-year lag, e.g., citations for 1995 are references made in articles in 1995 data tape to articles in 1991–93 data tapes. See appendix table 5-33 for countries/economies included in each region.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

Science and Engineering Indicators 2008

Figure 5-33
S&E articles and citations in all fields, by selected region/country: 1995 and 2005



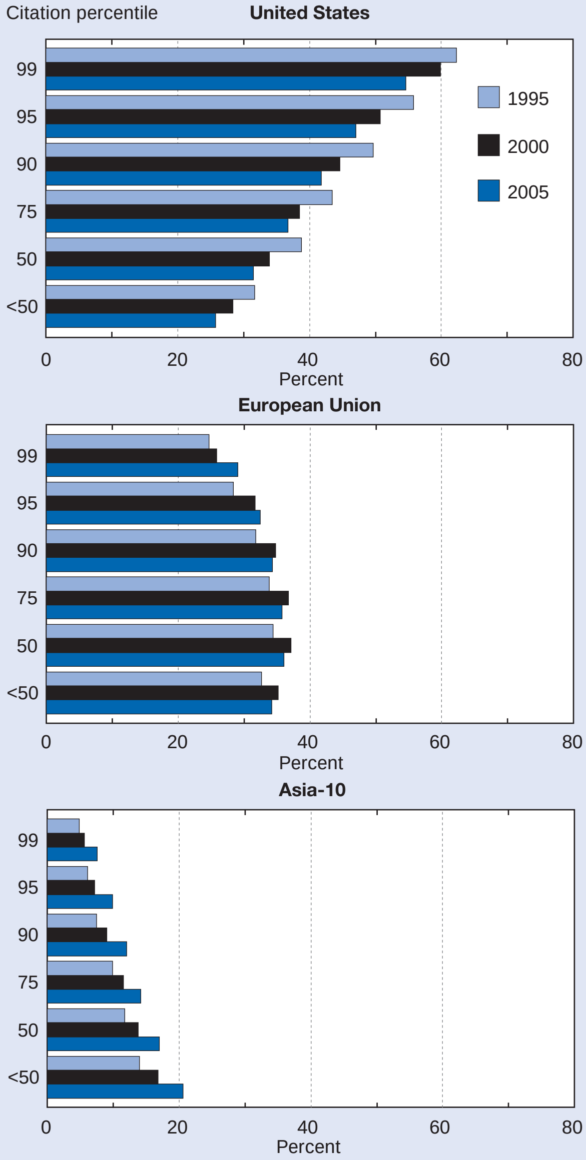
EU = European Union

NOTES: Share of all articles based on 3-year period. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles and citations on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Citation data based on year article entered database. Citation counts based on 3-year period with 2-year lag, e.g., citations for 1995 are references made in articles in 1995 data tape to articles in 1991–93 data tapes. See appendix table 5-33 for countries/economies included in EU and Asia-10.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-39 and table 5-28.

Science and Engineering Indicators 2008

Figure 5-34
United States, European Union, and Asia-10 share of cited papers, by citation percentile: 1995, 2000, and 2005

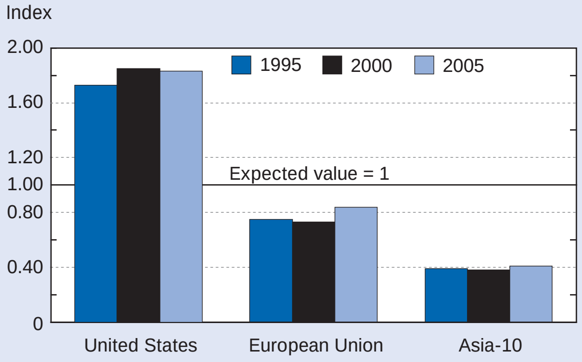


NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-33 for countries/economies included in European Union and Asia-10. Citation counts based on 3-year period with 2-year lag, e.g., citations for 1995 are references made in articles in 1995 data tape to articles in 1991–93 data tapes. Percentiles approximate because of method of counting citations and always higher than stated.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-38.

Science and Engineering Indicators 2008

Figure 5-35
Index of highly cited articles, by selected region/country: 1995, 2000, and 2005



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Citation data based on year article entered database. Citation counts based on 3-year period with 2-year lag, e.g., citations for 1995 are references made in articles in 1995 data tape to articles in 1991–93 data tapes. Index of highly cited articles is country/economy's share of world's top 1% cited articles divided by its share of world articles for the cited year window. See appendix table 5-33 for countries/economies included in European Union and Asia-10.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-38.

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0.41. In other words, the United States had 83% more articles than expected in the 99th percentile of cited articles in 2005, while the European Union had 16% fewer than expected and the Asia-10 had 59% fewer than expected.[46]

The United States experienced notable gains on the index of highly cited articles in engineering, mathematics, and computer sciences (although with relatively low counts in the latter) and declines in chemistry and geosciences (appendix table 5-39). The European Union experienced gains on the index in astronomy, chemistry, and geosciences and reached expectation only in agricultural sciences. The Asia-10 achieved increases in a number of fields, including engineering, chemistry, physics, and geosciences, but did not progress in the biological or medical sciences. The Asia-10's index score nearest expectation was in mathematics, at 0.79.

Academic Patents, Licenses, Royalties, and Startups

Other indicators of academic R&D outputs reflect universities' efforts to capitalize on their intellectual property in the form of patents and associated activities.[47] Although some U.S. universities were granted patents much earlier, the majority did not become actively involved in the management of their own intellectual property until late in the 20th century.[48] The Bayh-Dole Act of 1980 gave colleges and universities ownership of income streams from patented discoveries that resulted from their federally funded research. To facilitate the conversion of new knowledge produced in their laboratories to patent-protected public knowledge that can be potentially licensed by others or form the basis for a startup firm, more and more research institutions established technology management/transfer offices.

Efforts to encourage links between university-based research and commercial exploitation of the results of that research have been widely studied by researchers. Mowery (2002) notes the strong growth in funding by NIH and the predominance of biomedical-related patenting by universities in the 1990s. Branstetter and Ogura (2005) identify a "bio-nexus" in patent-to-paper citations, and Owen-Smith and Powell (2003) explore the effects of an academic medical center as part of the "scientific capacity" of a research university. In a qualitative study of two research universities that would appear to have similar capacities, Owen-Smith and Powell (2001) examine the very different rates of invention disclosure of the two campuses. Stephan and colleagues (2007) found strong differences in patenting activity among university scientists by field of science; a strong relationship between publication activity and patenting by individual researchers; and patenting among university researchers restricted to a small set of the potential population.

The following sections discuss overall trends in university patenting through 2005 and related indicators.

University Patenting Trends

U.S. Patent and Trademark Office (USPTO) data show that patent grants to universities and colleges increased sharply from 1995 to about 2002, when they peaked at just under 3,300 patents per year, and then fell to about 2,700 in 2005 (appendix table 5-40).[49] (However, this decline contrasts with recent increases in the related indicators of invention disclosures and patent applications filed by academic institutions, which are discussed in the next section, "Patent-related activities and income.") The top R&D-performing institutions, with 95% of the total, dominate among universities and university systems receiving patent protection.[50] College and university patenting as a percentage of U.S. nongovernmental patents grew in the 1980s and 1990s from less than 2% to just under 5%, and then declined to about 4.2% by 2005 (figure 5-36).

The previous edition of *Indicators* noted that three biomedically related utility classes dominated university patenting in the 1980s and 1990s (NSB 2006, pp. 5-54 and 5-55). In 2005, these same three classes together accounted for more than one-third of all utility patents awarded to U.S. academic institutions: drug, bio-affecting and body treating compositions (15.4%); chemistry: molecular biology and microbiology (13.8%); and organic compounds (5.6%) (appendix table 5-41). Other medical and life sciences-related classes of patents, although smaller than the top three in number of patents awarded, also ranked high on the list of top patent utility classes awarded to universities.

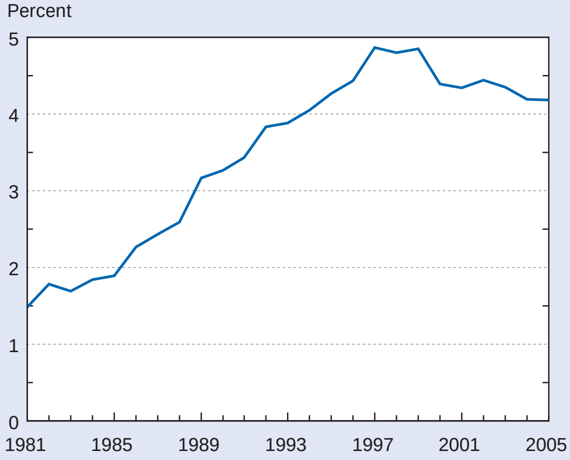
Patent-Related Activities and Income

In contrast to the USPTO-reported decline in the total number of patents awarded to U.S. universities and colleges in 2004 and 2005 (appendix table 5-40), data from the Association of University Technology Managers (AUTM) indicate continuing growth in a number of related activities. Invention disclosures filed with university technology management offices describe prospective inventions and are submitted before a patent application is filed. These grew from 13,700 in 2003 to 15,400 in 2005 (notwithstanding a small decline in respondent institutions to the AUTM survey over the same period) (appendix table 5-42). Likewise, new U.S. patent applications filed by the AUTM respondents also increased, from 7,200 in 2003 to 9,500 in 2004 and 9,300 in 2005 (appendix table 5-42).

Most royalties from licensing agreements accrue to relatively few patents and relatively few of the universities that hold them, and many of the AUTM respondent offices report negative income. (Thursby and colleagues [2001] note that the objectives of university technology management offices include more than royalty income.) At the same time, one-time payments to one university can complicate analysis of the overall trend in university income due to patenting. The *median* net royalty per university respondent to the AUTM surveys has both risen and fallen since 1996 but overall climbed from $440,000 in 1996 to $950,000 in 2005 (figure 5-37).

During the same period, the inventory of revenue-generating licenses and options across all AUTM respondent institutions increased, from 5,000 in 1996 to more than

Figure 5-36
U.S. academic share of patenting by U.S. private and nonprofit sectors: 1981–2005



NOTES: Patents issued by U.S. Patent and Trademark Office (USPTO) to U.S. universities and corporations. U.S. private and nonprofit sectors include U.S. corporations (issued bulk of patents in this category), nonprofits, small businesses, and educational institutions.

SOURCES: USPTO, Technology Assessment and Forecast Report: U.S. Colleges and Universities, Utility Patent Grants, 1969–2005 (2007); and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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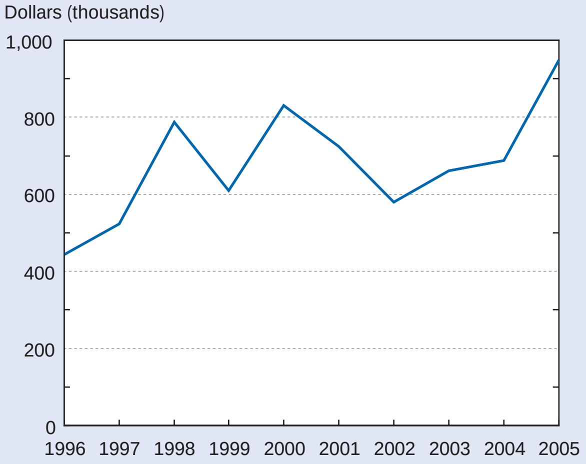
Figure 5-37
Median net royalties from academic patenting activities: 1996–2005



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

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10,200 in 2005 (appendix table 5-42). New licenses and options executed grew steadily to more than 4,000/year in both 2004 and 2005. The annual number of startup companies established as a result of university-based inventions rebounded after 2 years of downturns in 2002 and 2003 to more than 400 in both 2004 and 2005.

Conclusion

U.S. universities and colleges continued to be important participants in U.S. R&D during the first decade of the 21st century, performing more than half the basic research nationwide and having a significant presence in applied research. Funding of academic R&D from all major sources and across all broad S&E fields continued to expand. Since 2000, average annual growth in R&D has been stronger for the academic sector than for any other R&D-performing sector. Both the overall academic S&E doctoral workforce and the academic research workforce have also continued to increase. Citation data indicate that U.S. scientific publications remain highly influential relative to those of other countries. However, the relative volume of U.S. article output has not kept up with the increasing outputs of the European Union and the Asia-10. In fact, the number of U.S. articles published in the world's leading S&E journals has only recently begun to increase again after being essentially level since the early to mid-1990s.

Although funding for academic R&D has been increasing, a number of shifts in funding sources have occurred, the long-term implications of which are uncertain. After increasing between 2000 and 2004, the federal government's share of funding for academic R&D began to decrease in 2005 and again in 2006. In addition, for the first time since 1982, federal funding did not keep pace with inflation. Industry support for academic R&D, after growing faster than any other source of support through the turn of the century, declined in real absolute dollars for 3 successive years before rising again in both 2005 and 2006. The state and local share of support for academic R&D reached an all-time low in 2006. Research-performing universities have increased the amount of their own funds devoted to research every year since 1993.

The structure and organization of academic R&D have also changed. Research-performing colleges and universities continued to expand their stock of research space, particularly in the biological and medical sciences. However, spending on research equipment as a share of all R&D expenditures declined to an all-time low of 4.0% by 2006. With regard to personnel, a researcher pool has grown, independent of growth in the faculty ranks, as academic employment continued a long-term shift toward greater relative use of nonfaculty appointments. This shift has been marked by a substantial increase in the number of postdocs over a long period. These changes occurred during a period in which both the median age of the academic workforce and the percentage of that workforce age 65 or older have risen.

A demographic shift in academic employment has also been under way, with increases in the proportion of women, Asians/Pacific Islanders, and underrepresented minorities in the S&E academic workforce. This shift is expected to continue into the future. Among degree holders who are U.S. citizens, white males have been earning a decreasing 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 doctorate holders were more likely to enter academia than white males. A more demographically diverse faculty, by offering more varied role models, may attract students from a broader range of backgrounds to S&E careers.

Academic R&D is also becoming more international in a number of ways. U.S. academic scientists and engineers are collaborating extensively with colleagues in other countries: in 2005, more than one in four journal articles with a U.S. author also had at least one coauthor from abroad. The intimate linkage between research and U.S. graduate education, regarded as a model by other countries, helps to bring large numbers of foreign students to the United States, many of whom stay after graduation. Academia has also been able to attract many talented foreign-born scientists and engineers into its workforce, with the percentage of foreign-born full-time doctoral S&E faculty in research institutions approaching half the total in some fields.

Notes

1. Federally funded research and development centers (FFRDCs) associated with universities are tallied separately and are 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.

2. 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.

3. 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 between basic research, applied research, and development.

4. The academic R&D reported here includes separately budgeted R&D and related recovered indirect costs, as well as institutional estimates of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing.

5. Federal grants and contracts and awards from other sources that are passed through state and local governments to academic institutions are credited to the original provider of the funds.

6. 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.

7. It also likely includes some amount of research funding from the above-named sources that universities are unable to accurately code for reporting to the Academic R&D Survey of Research and Development Expenditures at Universities and Colleges.

8. The medical sciences include fields such as pharmacy, neuroscience, oncology, and pediatrics. The biological sciences include fields such as microbiology, genetics, epidemiology, and pathology. These distinctions may be blurred at times because boundaries between fields often are not well defined.

9. In this section of the chapter and section, "Doctoral Scientists and Engineers in Academia," the broad S&E fields refer to the computer sciences, environmental sciences (sometimes referred to as "earth, atmospheric, and ocean sciences"), life sciences, mathematical sciences, physical sciences, psychology, social sciences, other sciences (those not elsewhere classified), and engineering. The more disaggregated S&E fields are referred to as "subfields." The third section, "Outputs of S&E Research: Articles and Patents," groups the broad fields and subfields slightly differently (see sidebar, "Bibliometric Data and Terminology" and appendix table 5-32).

10. The discussion of federal support for academic R&D in the previous section is based on reporting by performer, i.e., academic institutions. This section is based on reporting by funder—the government agencies that provide R&D support to academic institutions. Performing and funding series may differ for many reasons. For a more detailed discussion of the differences between these two sources, see chapter 4 sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

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 Directorate of Science and Technology 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 DHS partners in this endeavor.

12. Another hypothesis is that some of the difference may be due to many public universities not having the incentive to negotiate full recovery of indirect costs of research because the funds are frequently captured by state governments.

13. Although the number of institutions receiving federal R&D support between 1973 and 1994 increased overall, a rather large decline occurred in the early 1980s, most likely due to the fall in federal R&D funding for the social sciences during that period.

14. Part of the decline in R&D equipment intensity may be due to a threshold effect, i.e., institutions not reporting purchases of equipment under a certain dollar threshold. There is some evidence that the minimum dollar value at which purchases of research equipment are reported in the Survey of Research and Development Expenditures at Universities and Colleges has been increasing over the years, leading to some equipment that would have been reported in earlier years not being reported in more recent years.

15. Research-performing academic institutions are defined as colleges and universities that grant degrees in science or engineering and expend at least $1 million in R&D funds. Each institution's R&D expenditure is determined through the NSF Survey of Research and Development Expenditures at Universities and Colleges.

16. Research space here is defined as the space used for sponsored R&D activities at academic institutions that is separately budgeted and accounted for. Research space is measured in NASF, the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls. Multipurpose space that is at least partially used for research is prorated to reflect the proportion of time and use devoted to research.

17. Some of this space will likely replace existing space and therefore will not be a net addition to existing stock.

18. Institutional funds may include operating funds, endowments, tax-exempt bonds and other debt financing, indirect costs recovered from federal grants/contracts, and private donations.

19. Some additional indirect federal funding may come through overhead on grants and/or contracts from the federal government. To the extent these funds are ultimately used for renovation or construction of facilities, they are reported as institutional funding because it is the institution that decides how they are spent.

20. Discussion of cyberinfrastructure is limited to networking because the Survey of Science and Engineering Research Facilities addresses only computing and networking capacity for research and instructional activities rather than all facets of cyberinfrastructure.

21. The "bricks and mortar" section of the Survey of Science and Engineering Research Facilities asks institutions to report on their research space only. The reported figures therefore do not include space used for other purposes such as instruction or administration. In the cyberinfrastructure section of the survey, however, respondents were asked to identify all of their cyberinfrastructure resources, regardless of whether these resources were used for research.

22. There have been discussions of a possible merger of Abilene and National Lambda Rail.

23. 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 associates, and administrators; and part-time positions of all kinds. Academic employment is limited to those employed in 2-year or 4-year colleges or universities. 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.

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

25. These data include only U.S.-trained postdocs. The number of postdocs with temporary visas and presumed non-U.S. doctorates increased greatly in the 1990s. For data on trends in U.S.- and foreign-trained postdocs in U.S. academic institutions, see the discussion of postdocs in chapter 2. For more information on employment aspects of postdoctoral appointments, see the discussion of postdocs in chapter 3.

26. The inclusion or exclusion of those on temporary and permanent visas has little impact on the analysis (see figure 5-20).

27. 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 doctorates from universities outside the United States are not included in the analysis.

28. 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.

29. This measure was constructed slightly differently in the 1980s and in the 1990s, starting in 1993, and is not strictly comparable across these periods. In the 1980s, the survey question asked the respondent to select the primary and secondary work activity from a list of activities. Beginning in 1993, respondents were asked on which activity they spent the most hours and on which they spent the second most hours. Therefore, the crossing over of the two trends between 1991 and 1993 could partly reflect a difference in methodology. However, the faster growth rate for researchers in both the 1973–91 and 1993–2006 periods means that changes in question wording cannot fully explain the observed trend. Because individuals may select both a primary and a secondary work activity, they can be counted in both groups.

30. The data in this edition of *Indicators* do not include articles from journals in professional fields. Thus the article counts reported here for past years will be slightly lower than counts reported in previous editions. See sidebar, "Bibliometric Data and Terminology."

31. European Union (EU) data include all member states as of 2007 (see appendix table 5-33 for a list of member countries); previous editions of *Indicators* considered a smaller set. Thus the larger world share of S&E articles accounted for by the European Union is in no small part a result of the expanded EU membership. However, see the discussion of growth rates by region and country later in this section.

32. The Asia-10 includes China (including Hong Kong), Japan, India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand, and Taiwan.

33. Uzun (2006) describes 20 years of Turkish science and technology policies that underlie the expansion of its article output.

34. Another use of these data, showing within-country/within-region S&E article field distributions as an indicator of the region/country portfolio of S&E research, has been discussed in past editions of *Indicators*. Although countries and regions display somewhat different emphases in their research portfolios, these patterns are stable and change only slowly over time. See, for example, *Science and Engineering Indicators 2006,* figure 5-38 and appendix tables 5-44 and 5-45 (NSB 2006).

35. The reader is reminded that the data on which these indicators are based give the nationality of the institutional addresses listed on the article. Authors are not associated with a particular institution and may be of any nationality. Therefore the discussion in this section is based on the nationality of the institutions, not authors themselves and, for practical purposes, makes no distinction between nationality of institutions and nationality of authors.

36. Merton (1973, p. 409) points out the tension between the norms of priority and of allocating credit in science: "Although the facts are far from conclusive, this continuing change in the social structure of research, as registered by publications, seems to make for a greater concern among scientists with the question of 'how will my contribution be identified' in collaborative work than with the historically dominant pattern of wanting to ensure their priority over others in the field…It may be that institutionally induced concern with priority is becoming overshadowed by

the structurally induced concern with the allocation of credit among collaborators."

37. In this section only, author names refer to counts of individually listed authors of articles, not institutional authors. Since authors may appear on more than one article per year, they may be counted more than once. However, because NSF does not analyze individual author names, the extent of such multiple counting is unknown.

38. The coauthorship data discussed in this paragraph are restricted to coauthorship across the regions/countries identified in table 5-23; i.e., collaboration between or among countries of the European Union, for example, is ignored. *Intraregional* coauthorship is discussed in the following sections.

39. Readers are reminded that each country participating in an international coauthorship receives one full count for the article; i.e., for an article coauthored by the United States and Canada, both the United States and Canada receive a count of one. In the percentages discussed in this paragraph, the numerators for the country pairs are the same. The denominators vary, accounting for the different rates of coauthorship.

40. Readers are reminded that the *number* of coauthored articles between any pair of countries is the same; each country is counted once per article in these data. However, countries other than the pairs discussed here may also appear on the article.

41. Identification of the sector of the non-U.S. institution is not possible with the current data set.

42. Readers are reminded that coauthors from different departments in an institution are coded as different institutions.

43. See note 42.

44. This chapter uses the convention of a 3-year citation window with a 2-year lag, e.g., 2005 citation rates are from references in articles in the 2005 tape year to articles on the 2001, 2002, and 2003 tapes of the Thomson Scientific Science Citation Index and Social Sciences Citation Index databases. Analysis of the citation data shows that, in general, the 2-year citing lag captures the 3 peak cited years for most fields, with the following exceptions: in astronomy and physics the peak cited years are generally captured with a 1-year lag, and in computer sciences, psychology, and social sciences with a 3-year lag.

45. Percentiles are specified percentages below which the remainder of the articles falls, for example, the 99th percentile identifies the number of citations 99% of the articles failed to receive. Across all fields of science, 99% of articles failed to receive at least 21 citations. Matching numbers of citations with a citation percentile is not precise because all articles with a specified number of citations must be counted the same. Therefore, the citation percentiles discussed in this section and used in appendix table 5-38 have all been conservatively counted, and the identified percentile is in every case higher than specified, i.e., the 99th percentile is always >99%, the 95th percentile is always >95%, etc. Actual citations/percentiles per field vary widely because counts were cut off to remain in the identified percentile. Using this method of counting, for example, the 75th percentile for engineering contained articles with two citations, whereas the 75th percentile for biological sciences contained articles with 5–8 citations.

46. This pattern holds for even lower citation percentiles (e.g., the 95th or 90th).

47. The previous edition of *Indicators* discussed various factors that may have contributed to the rise in university patenting, including federal statutes and court decisions (see NSB 2006, p 5-51 through 5-53).

48. For an overview of these developments in the 20th century, see Mowery (2002).

49. It is unclear whether the recent downturn in patents granted to universities/colleges is a result of changes in processing at the U.S. Patent and Trademark Office (USPTO). For example, in its Performance and Accountability Report Fiscal Year 2006, USPTO reported an increase in overall applications from 2002 to 2006; a decrease in "allowed" patent applications; and an increase in average processing time from 24 to 31 months (USPTO 2006).

50. The institutions listed in appendix table 5-40 have been reported consistently by USPTO since 1982. Nevertheless some imprecision is present in the data. Several university systems are counted as one institution, medical schools may be counted with their home institution, and universities are credited for patents only if they are the first-name assignee on a patent; other assignees are not counted. Universities also vary in how they assign patents, e.g., to boards of regents, individual campuses, or entities with or without affiliation with the university.

Glossary

Abilene: A high-performance network dedicated to research led by a consortium of universities, governments, and private industry; often called Internet2.

Academic doctoral S&E workforce: Includes those with a U.S. doctorate in an S&E field employed in 2- or 4-year colleges or universities 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 associates, and administrators; and part-time positions of all kinds.

Academic institution: In the "Financial Resources for Academic R&D" section of this chapter, 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. Elsewhere in the chapter, this term encompasses any accredited institution of higher education.

Asia-10: Asia-10 includes China (including Hong Kong), India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand.

Coauthored articles: In the "Outputs of S&E Research: Articles and Patents" section of this chapter, a paper is considered coauthored only if its authors have different institutional affiliations or are from separate departments of the same institution. See *institutional author*.

Cyberinfrastructure: Infrastructure based on distributed computer, information, and communications technology.

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

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

Fractional counting: A method of counting articles based on authorship attribution. Fractional counting divides the credit for an article with authors from more than one institution or country among the collaborating institutions or countries, based on the proportion of their participating departments or institutions. This method is generally used for article and citation counts.

Index of highly cited articles: A country's share of the world's top 1% of cited articles divided by its world share of articles during a given period.

Index of international collaboration: A country's rate of collaboration with another country divided by the other country's rate of international coauthorship.

Institutional author: Designation of authorship according to the author's institutional affiliation at the time of publication. Institutional authorship is used to determine the number of institutional authors an article has for purposes of article counts. Multiple authors from the same department of an institution are considered as one institutional author. See *fractional counting* and *whole counting*.

National Lambda Rail: A national fiber optic infrastructure supporting multiple networks for the research community.

Net assignable square feet (NASF): Unit for measuring research space. NASF is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls.

Research space: The space used for sponsored R&D activities at academic institutions that is separately budgeted and accounted for.

Tape year: The year an article entered the publication database, which may be later than the year the article was published.

Underrepresented minority: Demographic category including blacks, Hispanics, and American Indians/Alaska Natives, groups considered to be underrepresented in academic institutions.

Whole counting: A method of counting articles based on authorship attribution. Whole counting assigns each collaborating institution or country one credit for its participation in an article. This method is generally used for coauthorship data.

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