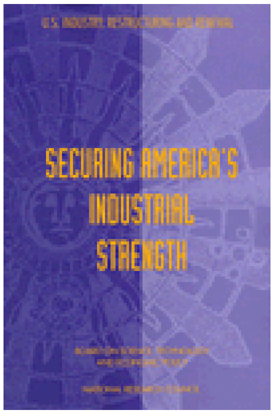


**Securing America's Industrial Strength**

Board on Science, Technology, and Economic Policy, National Research Council

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# SECURING AMERICA'S INDUSTRIAL STRENGTH

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*Cover*: The emblem appearing on the cover of this publication is an illustration of the bronze medallion in the floor of the Great Hall in the National Academy of Sciences building in Washington, D.C. The medallion is the wellhead placed in the floor when the spectroscopic case over which the Foucault pendulum swings is lowered below floor level. The design is based on a map of the solar system published in 1661 by Andreas Cellarius Palatinus. The array of the planets is the Copernican system as known to Galileo.



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BOARD ON SCIENCE, TECHNOLOGY, AND ECONOMIC POLICY**

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# Preface

In 1991 the National Academies of Sciences and Engineering established the Board on Science, Technology, and Economic Policy as a forum in which economists, technologists, scientists, financial and management experts, and policymakers could broaden and deepen understanding of the relationships between science and technology and economic performance. In its first three years, the Board's activities focused on the adequacy and efficiency of public and private domestic investment in physical and human capital. The Board's first report, *Investing for Productivity and Prosperity*, underscored the need for higher rates of national saving and investment. Its principal recommendation was to shift the base for taxation from income to consumption.

In the past three years, the Board has turned its attention to more microeconomic concerns—technology policies broadly defined and their relationship to international trade relations, determinants of competitive performance in a wide range of manufacturing and service industries, and changes in patterns of R&D and innovation investments. A series of conferences, workshops, and reports, of which this volume is the fourth, comprises the latter body of STEP work which we are calling, *U.S. Industry: Restructuring and Renewal*, because it represents a broad assessment of U.S. industrial performance in an international context at a time of domestic economic confidence and optimism but uncertainty about the consequences of fundamental changes in the composition of the economy, processes of innovation, and economic troubles abroad. Previous publications under this title include *Industrial Research and Innovation Indicators*, the report of a workshop on measurement of industrial research and innovation, and *Borderline Case: International Tax Policy, Corporate Research and Development and Invest-*

*ment*, a collection of papers by leading tax scholars, practitioners, and policy analysts.

The third volume in this series, a companion volume to this report, *U.S. Industry in 2000: Studies in Competitive Performance*, is a collection of papers commissioned by the STEP Board and originally presented at a conference, "America's Industrial Resurgence: Sources and Prospects," held at the National Academy of Sciences in Washington, D.C., on December 8–9, 1997. The chapters analyze the determinants of performance on several dimensions including international competitiveness in 11 manufacturing and nonmanufacturing industries in the United States over the past 15 or 20 years. The single exception was an analysis of shifts in comparative advantage in the chemical industry over four producing countries and a 150-year period. An introduction by David Mowery, professor at the Haas School of Business at the University of California at Berkeley, who edited the papers, synthesizes some of the conclusions from examining cases as diverse as steel, apparel, semiconductors, banking, and trucking.

In this report the STEP Board observes that the general picture is one of stronger performance in the 1990s than in the early 1980s, attributable to a variety of factors including supportive public policies, competition and openness to innovation, and changes in supplier and customer relationships. Vigorous foreign competition forced changes in manufacturing processes, organization, and strategy but then receded, making the performance of U.S. industries look even better. None of these favorable conditions, least of all the latter, however, is permanent. U.S. industries' superior records in the past decade are not guaranteed to continue. In addition to its conclusions about factors contributing to improved performance in the 1990s, the Board identifies several concerns for the future.

This report and the series of activities preceding it would not have been possible without the financial support of the National Aeronautics and Space Administration and National Science Foundation and the personal encouragement of Daniel Goldin, NASA Administrator. Additional funds for the conference and publication of industry studies were provided by the Office of Industrial Technologies of the U.S. Department of Energy, the Alfred P. Sloan Foundation, Ralph Landau, and the Lockheed Martin Corporation.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their participation in the review of this report: Wesley Cohen, Carnegie Mellon University; Robert Frosch, Harvard University John F. Kennedy School of Government; Robert Hermann,

Global Technology Partners, LLC; Anita McGahan, Harvard University Graduate School of Business; David Mowery, University of California at Berkeley Haas School of Business; Richard Rosenbloom, Harvard University Graduate School of Business Emeritus. France Cordova, Vice Chancellor for Research at the University of California at Santa Barbara, coordinated the review for the Policy Division.

Although the individuals listed above have provided constructive comments and suggestions, responsibility for the final content of this report rests entirely with the authors, the STEP Board, and the institution.

A. Michael Spence
*Chairman (until June 30, 1998)*

Dale W. Jorgenson
*Chairman (after July 1, 1998)*

Stephen A. Merrill
*Executive Director and*
*Project Director*

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# Securing America's Industrial Strength

## EXECUTIVE SUMMARY

Through the 1980s a series of studies portrayed the technological leadership and international competitiveness of U.S. manufacturing industries as imperiled and probably on the decline. Only a decade later, trends seem to have been reversed and the prospects for continued strong U.S. economic performance appear bright. Were American industries and firms really doing that poorly and foreign competitors that well a decade ago? Is the apparent reversal an accurate picture and will U.S. technological leadership and competitive strength across a broad range of industries be sustained?

To help answer these questions, the National Research Council's Science, Technology, and Economic Policy (STEP) Board commissioned studies of eleven industries, including so-called "service" industries that were overlooked in the competitiveness debate because manufacturing was considered to be the backbone of the economy and more vulnerable. Today, services generate three-quarters of the gross domestic product, employ eighty percent or more of the workforce, and consume much of manufacturing output (e.g., commercial aircraft, medical products, and computers). The industries that the Board examined are steel, chemicals, pharmaceuticals and biotechnology, banking, trucking, food retailing, power metallurgy parts, apparel, computing, semiconductors, and computer disk drives. These studies appear in a companion STEP Board volume, *U.S. Industry in 2000: Studies in Competitive Performance,* with an introduction by David Mowery, University of California Haas School of Business.

Pessimistic analysts in the 1980s almost certainly mistook adverse macroeconomic trends—in particular, the high valuation of the dollar—for much more fundamental signs of structural deterioration. Nevertheless, the general picture is one of stronger performance in the 1990s on a variety of dimensions, among them investment, export market share, R&D spending, and profitability. Although not universal and not without dislocations to particular firms, groups of workers, and regions, this improvement is true of much of the service sector as well as manufacturing. Foreign competition has been a driver of change in some cases but not in all. Domestic competition, often from new entrants, has played an important role. In trucking, banking, food retailing, and most manufacturing industries, applications of information technology have enabled the introduction of new products and services and recasting of logistics and other processes to be more efficient.

Although precise causal relationships and rankings cannot be determined, in the 1990s the U.S. government followed a supportive mix of macroeconomic and microeconomic policies—deficit reduction, conservative monetary policy, scaling back of economic regulation of transportation, finance, and communications, trade liberalization, relatively permissive antitrust enforcement, and strengthening of intellectual property rights. As it had in previous decades, the federal government continued to support research across a broad range of scientific and engineering fields, although the 1990s saw the beginning of a change in the research portfolio that may not bode well for the future—in particular, a decline in support of several physical science and engineering fields.

Improved U.S. industrial performance also reflects a variety of private sector strategies—repositioning, product specialization, firm consolidation, internationalization of operations, manufacturing process improvement, and cost reduction—that were market driven, not guided by public policies. These benefited some established firms at the expense of others and in many industries opened opportunities for new entrants. As a result, on the eve of 2000 the structure of most industries looks very different than it did even 15 years ago.

Several enduring characteristics of the American political system and economy bode well for the future—the sheer size of the domestic market, encouragement of experimentation, and relatively little protection accorded enterprises resistant to change. Indeed, contrary to recent conventional wisdom about investors' myopia, U.S. capital markets over time do a reasonably good job of favoring firms with high growth prospects.

Nevertheless, in the long run international shifts in comparative advantage are inevitable, as a result of changes in national political, legal, educational, and capital market institutions, wars and other destabilizing events. Today, Americans should be wary of assuming that the 1990s marked an enduring turnaround in U.S. industry performance.

Despite its general satisfaction with the progress of the last decade and guarded optimism about the future, the STEP Board concludes from its investigations that there are four policy concerns that need to be addressed:

- Carefully selected indicators and data collected nationally on a recurring basis are needed to help discern and track changes in industry structure and innovation processes and to help design and evaluate public policies affecting innovation. Current science and technology indicators and data fall woefully short of illuminating changes that are known or believed to have occurred in the 1980s and 1990s. Although questions of feasibility, reporting burden, and cost need to be examined, the STEP Board believes that, in principle, a number of steps should be taken to improve the information base for microeconomic policy design and evaluation. These include collecting data at the business-unit level of the firm, conducting innovation and technology adoption surveys, linking datasets to one another, exploiting data on the training, career paths, and work of technically trained people, and exploring public-private partnerships to produce information useful to both corporate managers and public policymakers.

- Lack of an adequate, well-trained workforce—particularly those skilled in creating, developing, and deploying information technologies—may inhibit the capacity of the United States to remain prosperous and a locus of innovation. Immigration quotas have been raised, some states, educational institutions, and firms are expanding degree and training programs, and companies are paying higher premiums for skilled labor or seeking it abroad. What is not clear is whether, despite these measures, there will remain a growth-limiting shortfall between supply and demand and what additional steps, if any, should be taken to alleviate it.

- Strengthening and extending intellectual property rights (IPRs)—conferred by patents, copyrights, and penalties for misappropriating trade secrets—are appropriate policies for advanced industrial economies where intellectual assets are the principal source of growth. It may be that in some respects these processes should be taken further than the many steps accomplished in the past 25 years. On the other hand, there is growing friction over the assertion and exercise of IPRs and claims that in some circumstances they may be discouraging research, its communication, and use. The question arises whether in some respects IPR strengthening and extension have proceeded too far.

- The Board's case studies and limited national data suggest that the improved competitive performance of at least some of the industries reliant on the physical and information sciences, engineering, and mathematics—electronics, software, networking, and materials processing—has come about in the face of reductions in industry-funded longer-range research. Since 1992, public investment in research in several of these fields has also declined as a result of budget reduction pressures and changing federal agency missions. These trends are of sufficient concern to merit a careful assessment of their long-term implications and what steps, if any, should be taken to change them.

## FROM "PERVASIVE DECLINE" IN THE 1980S TO "RESURGENCE" IN THE 1990S

In the 1980s a series of studies portrayed the technological leadership and international competitiveness of U.S. manufacturing industries as imperiled and probably on the decline. While acknowledging U.S. strengths in academic research, the education of scientists and engineers, technological development, and venture capital financing of technology-based start-up firms, the studies observed serious weaknesses in the capacity of American corporations, compared with their Japanese competitors, to turn these first-class assets into advanced processes and commercially successful products. One study went so far as to characterize the decline of U.S. manufacturing as "systematic and pervasive" (Dertouzos et al., 1989), another as "a major historical development for this country" (Eckstein et al., 1984). The studies made several diagnoses, not mutually exclusive.

It was widely believed that, despite exceptional cases such as biotechnology, U.S. firms were underinvesting in general and, in particular, shying away from new ventures with longer time horizons but the promise of eventual competitive advantage, market share gains, higher returns, and even the creation of new industries. Different analysts emphasized different sources of this risk-averse behavior—among them, low national saving rates and a higher cost of capital or required return on investments ("hurdle rates") than faced by competitors in other countries. Others decried Wall Street's dictate that corporate managers show quarterly growth in profits to maintain stock prices, a lack of "patient" capital available to Japanese or German competitors through the substantial bank holdings in industrial corporations, and the inability of managers in some U.S. industries such as semiconductors to spread the risk of new technology development across the range of businesses allied in the typical Japanese keiretsu or Korean chaebol.

There was a great deal of concern that barriers to foreign market access and investment, dumping of products in third markets, public subsidies to firms and consortia engaged in technology development, and protection of mature industries from competition put U.S. companies at a serious competitive disadvantage.

A perceived neglect of process research and development (R&D) and product quality by U.S. firms was attributed to poor management education and technical training as well as to investment disincentives. As a result, many observers claimed, quality across a range of products from automobiles to semiconductors was suffering and customers were turning to more reliable non-U.S. sources.

Inferior precollege public education, preparation of school-leavers for work, and career-long training and simply the lack of culturally ingrained habits of cooperation were cited as long-term U.S. disadvantages.

Only a decade after the last of these reports, the public mood and tone of academic analysis of the American economy are generally upbeat, buoyed by seven years of uninterrupted growth, low inflation, record job creation, low unemployment, and the first federal budget surplus in more than 30 years. Concerns about the competitiveness of American industries have receded even further as a result of the prolonged stagnation of the Japanese economy and the ensuing crisis slowing the economies of Korea, Singapore, Taiwan, and other Asian countries. In the rush to find fault with the Asian countries' economic and political systems, their remarkable growth performance over a generation is subordinated to their current economic problems.

Striking examples of this reversal in thinking since the late 1980s are the industry-by-industry assessments of the Massachusetts Institute of Technology's (MIT) Commission on Industrial Productivity, Data Resources, Inc. (DRI), and the National Academy of Engineering (NAE) contrasted with contemporary studies of the same industries under the auspices of the STEP Board:

*Pharmaceuticals...*

> The... industry has maintained an image of immunity from the deterioration of competitive advantage besetting many sectors of the American economy, such as automobiles, steel, textiles and consumer electronics. Unfortunately, this image is apparently exaggerated and probably false. Data compiled by this study indicate a clear relative deterioration in the foundation of pharmaceutical competitive positions—the research efforts necessary for discovery and introduction of new patented drugs....A declining U.S. share of a growing industry is as much a concern for U.S. industrial policy as a declining share of an industry undergoing retrenchment. (NAE, 1983)
>
> ...The industry has been by almost any measure outstandingly successful...one of the few industries that American firms have dominated almost since its inception, and one in which American firms continue to have an indisputable lead. During the 1980s and 1990s double digit rates of growth in earnings and return on equity were the norm for most pharmaceutical companies...(Cockburn et al., 1999)

*Semiconductors...*

> The traditional structure and institutions of the U.S. industry appear to be inappropriate for meeting the challenge of the much stronger and better organized Japanese competition.... The technological edge that once enabled innovative American companies to excel despite their lack of financial and market clout has disappeared, and the Japanese have gained the lead (Dertouzos et al., 1989).

Since 1989 the market position and profitability of U.S. firms have improved, especially relative to those of Japanese firms. Stronger U.S. performance is revealed in gains in global market share that rest in part on improvements in product quality and manufacturing process yields. Improved performance also reflects the withdrawal of most U.S. firms from the fiercely competitive DRAM segment and shift to logic and micrcomponent products where they could pursue new product opportunities....The so-called "fabless" semiconductor firms have entered the industry successfully as specialists in innovative device designs (Macher et al., 1999).

*Chemicals…*

The international trade position of the chemical industry is eroding due to several factors. U.S. raw materials prices are rising to reach parity with the rest of the world....With the decontrol of oil and rising prices of natural gas, the cost advantage of U.S. petrochemical producers has gradually disappeared. Further, the chemical industry is losing markets because of the rising volume of imports of finished goods that are major chemical markets (automobiles, consumer electronics, and apparel). Finally, the decision of several OPEC countries... to develop basic petrochemical capacity will make a glut of capacity for some chemical commodities, such as methanol, ammonia, and ethylene, a very likely prospect (Eckstein et al., 1984).

In the 1980s, a far-reaching restructuring in the industry, consisting of divestitures and actions to focus firms on a narrower line of products and processes, contributed to improved results in many U.S. chemical firms. This restructuring process began earlier and has proceeded further in the U.S. chemical industry than in those of continental Europe and Japan (Arora et al., 1999).

*Computers…*

Although the U.S. computer industry remains strong, the outlook will not continue to be bright without strong initiatives. Computer builders in Japan, South Korea, and Taiwan are gaining the research and development, market research services, and technical skills they need to be strong international competitors. To ensure that the U.S. industry remains competitive as the challengers gain strength, production facilities need to be retained and upgraded....U.S. computer makers must also work cooperatively with domestic chip suppliers to ensure access to the latest microcircuit technologies....Software leadership is another important requirement, especially as Japan develops "software factories" and improves the programming tools that can make software development faster and more efficient (Dertouzos et al., 1989).

> Despite all the change, one element of continuity is remarkable. Despite the decline of once-dominant IBM, U.S. firms continue to dominate the rent-generating portions of the industry, such as packaged software, microprocessors, and networking. Although the U.S. share of overall industry revenue is slowly falling, rents are staying put. Consider Microsoft, Intel, and Cisco, a troika that is small in revenue but very large in rents and influence (Bresnahan, 1999).

Were U.S. industries and firms really doing that badly and foreign competitors performing that well a decade ago? Is the apparent reversal today an accurate picture? Although related, distinguishing macroeconomic fluctuations and generally slower moving microeconomic or structural changes is a difficult but necessary task. The tendency is to read the cyclical set of signals for the structural trends, especially when the macroeconomic environment is especially negative, as it was in the early 1980s, or positive, as in the late 1990s.

As for the future, will American industrial resurgence be sustained? Does the recent performance of a number of industries signify that they have permanently improved their comparative advantage and long-term growth prospects? Almost certainly the answer is that growth will not continue indefinitely in its current configuration or at its current rate. But even if we knew how to sustain resurgence and avoid recession, should we be satisfied with the status quo or should we aspire to a higher growth trajectory? What public policies and private-sector strategies would help achieve it? What current microeconomic trends may undermine it? What areas of ignorance need to be addressed?

## THE STEP BOARD'S ANALYSIS

To help answer these questions, the National Research Council's Board on Science, Technology, and Economic Policy (STEP) undertook an analysis in 1997 that had an ambitious objective and involved several components. The goal was to understand the role of technological and nontechnological factors in the generally improved performance and competitive status of American industries and the public policies contributing to that improvement on the assumption that such understanding could both help sustain growth and anticipate any extensive deterioration in performance.

The "technological versus nontechnological" distinction is a crude but useful way to underscore that technology and innovation, broadly conceived to include translation of prototypes into manufactured products and services, adoption of technologies from sources external to a firm, diffusion of incremental improvements in products and services, and investment in science and engineering talent and technical skills, as well as R&D, are responsible for perhaps one-quarter of economic growth in the postwar period. At the same time there are many other influences on economic performance—macroeconomic conditions; tax, regulatory, and other policies that affect industry sectors differently; education; legal institutions; corporate governance; and industry- and firm-level strategies. In the long run, these factors condition one another.

With respect to technological factors, of particular interest is the relationship of apparent changes in public and private investment to current and future economic performance. Among the changes frequently cited are the following:

- There has been a marked change in the public and private shares of research expenditures, from parity in 1980 to a ratio of more than twice as much industry as federal government investment today.
- Largely as a byproduct of the end of the cold war there has been a change in the defense and nondefense shares of the federal government's R&D portfolio, resulting in less support for most fields of the physical sciences and engineering absolutely and relative to the biological and medical sciences.
- At the same time changes in the composition and orientation of private-sector research and innovation are believed to include an apparent shortening of the time horizon of corporate planning, focus on incremental improvements in technology, greater corporate reliance on external sources of technology and collaborative arrangements with public and private institutions, domestic and foreign, and movement of R&D activity offshore or into regional concentrations of technology-intensive enterprises.
- In some sectors, goods production and service delivery have grown more dependent on technology and highly skilled labor but without an increase in formal R&D investment or much R&D activity at all.

Nontechnological influences on performance, too, have changed in greater or lesser degree in the past decade.

- Firms engaged primarily in the delivery of goods and services have come to dominate the economy, accounting for approximately three-quarters of the GDP and employment.
- Trade has become an integral part of the U.S. economy; exports and imports have increased from approximately 14 percent of GDP in 1980 to 25 percent in 1997.
- The occupational structure of the economy has changed with growth at both ends of the scale—managerial and professional jobs on the one hand and low-wage, low-skilled jobs on the other hand—while the share of mid-level skilled and paid jobs has declined.

The STEP Board has approached the tall order of sorting out these influences and effects from several different angles, including industry-level analysis, an examination of policy influences on corporate behavior, a review of trends in new venture financing, and an assessment of the adequacy of aggregate data, especially that relating to industrial innovation.

## Industry Studies

Like the authors of the 1980s studies mentioned earlier, the Board concluded that God as well as the devil is in the details of changes at the industry and, necessarily, firm levels. Under the leadership of STEP member Ralph Landau, the Board identified a number of centers of sectoral expertise that included studies of industry performance and innovation as a principal element. For the most part these are multidisciplinary research projects sponsored by the Alfred P. Sloan Foundation at various universities.

To try to standardize these case studies, the Board asked David Mowery of the Haas School of Business faculty at the University of California at Berkeley to develop a general framework to analyze the determinants of performance over the past 15 to 20 years. An exception was a study of the chemical industry, over 150 years and four countries, by Landau and Ashish Arora.[1] The shorter time period was chosen to frame the change in performance and also for reasons of economy, although we acknowledge, as the chemical industry study illustrates, that the analysis would benefit from a longer horizon. The Board then convened two workshops that included the investigators selected along with industry analysts from the U.S. Departments of Commerce and Energy, the U.S. International Trade Commission, trade associations, and other organizations. The resulting commissioned papers were presented at a conference in December 1997 at the National Academy of Sciences, where they were discussed with representatives of the subject industries, interested government officials, and other scholars. Revised versions of these papers appear in a companion volume to this report, *U.S. Industry in 2000: Studies in Competitive Performance.*

The group of industries examined (see Table 1) does not represent a sample carefully chosen to be representative of all major sectors of the economy. We were unable to recruit participants with the appropriate range of expertise to assess changes in the resource extraction industries—petroleum and mining—agriculture and forestry, and automobiles, the source of much of the initial concern about declining U.S. competitiveness in the 1970s. Individually and collectively, however, the industries are good candidates for studying transitions in performance among American firms over the past 20 years. Furthermore, they enabled us to capitalize on the cumulative work of analysts informed by close relations with firms in their subject industries and, in some cases, access to proprietary data.

[1]R. Landau and A. Arora, "The Dynamics of Long-Term Growth: Gaining and Losing Advantage in the Chemical Industry," in D. Mowery, ed., 1999. The authors adapted this chapter from their book-length study, *Chemical and Long-Term Economic Growth,* edited with Nathan Rosenberg (1998).

**TABLE 1** Industry Studies

| | *Segments* |
|---|---|
| *Materials processing* | |
| Chemicals | Commodity<br>Specialty |
| Steel | Integrated<br>Nonintegrated (minimills) |
| Powder metallurgy parts | |
| *Services* | |
| Trucking | Truckload (TL)<br>Less than truckload (LTL)<br>Package express |
| Food retailing | |
| Retail banking | |
| *Fabrication and Assembly* | |
| Computing | Mainframes<br>Minicomputers<br>Microcomputers (PCs)<br>Software<br>Networking |
| Hard disk drives | |
| Semiconductors | "Fabless" design<br>Memory devices<br>Microprocessors and customized devices |
| Apparel | Men's<br>Women's |
| Pharmaceuticals | |

In contrast to the MIT, DRI, and NAE studies, our selection includes three "service" industries—banking, trucking, and food retailing. Although the 1990s proved unfounded the fear that U.S. manufacturing as a whole is endangered and in need of rescue, it no longer makes sense to focus exclusively on manufacturing industries, ignoring by far the largest, increasingly international, and knowledge-intensive sector of the economy. Not only are services the dominant sector of the U.S. economy, generating three-quarters of the gross domestic product (GDP) and employing 80 percent of the work force—90 percent if service functions in the manufacturing sector are included (Survey of Current Business, 1998; U.S. Department of Labor, 1998), they are a major customer for manufacturers in general and the sole customers of products such as aircraft, pharmaceuticals, and medical equipment. Conversely, information technology as well as traditional services represent a critical part of the foundation for production of high-value-added manufactured goods. In any case, it is increasingly difficult to classify as manufacturing or services a significant range of economic activities, as many companies perform functions and pursue markets in both sectors. For example, contrast the MIT commission's characterization of the computer industry of the 1980s as composed of "makers" of mainframe computers, minicomputers, and microcomputers (with software as an afterthought) with the contemporary description by Timothy Bresnahan, author of the STEP Board's computing industry case study:

> A few pioneering firms once supplied computers; now there are hundreds of successful suppliers of components, software, systems, services, and networks. Performance increases and price decreases, dramatic improvements in all different complementary technologies, and considerable innovation and learning-by-using by customers, all woven together by firm, market, and other institutions for coordination, have built a multi-billion dollar worldwide industry (Bresnahan, 1999).

Industry analysts were asked, among other tasks, to identify and discuss the public policies that over the past two decades most strongly affected the structural evolution, technological development, and performance of the industry sectors they studied. Some of their findings are presented below.

## Other Study Elements

Other principal elements of the project included policy analysis, review of the financing of new firms, and evaluation of research and innovation indicators. The STEP Board decided to extend some of its earliest work on tax policy and corporate investment (National Research Council, 1994) to consider how incentives for R&D and U.S. tax rules governing international activities affect the investment behavior of technology-based multinational companies. Former STEP member James Poterba chaired a steering committee that commissioned papers from leading international tax scholars, practitioners, and policymakers and convened a conference in February 1997 to discuss the results. The papers have been published in *Borderline Case: International Tax Policy, Corporate Research and Development, and Investment* (Board on Science, Technology, and Economic Policy, 1997).

The Board collaborated with the National Academies' Committee on Science, Engineering, and Public Policy in organizing a workshop to examine the viability of capital, management expertise, and other assistance to technology-oriented entrepreneurs from "angel" financiers and organized venture capital funds. In addition to assessing the prospects for continued growth of venture capital markets, the workshop considered the fluctuations in investment in different technologies, especially information technology, biotechnology, and medical services. Former STEP member Burton J. McMurtry organized and co-chaired the meeting.

Finally, a steering committee chaired by Dale Jorgenson conducted a workshop to assess the adequacy, utility, and policy relevance of the government's data on industrial research and innovation. At the request of the National Science Foundation's Science Resources Studies (SRS) division, the workshop was also designed to generate suggestions for improving this information base. A report of the workshop, including participants' recommendations, *Industrial Research and Innovation Indicators* was published in 1997 (Cooper and Merrill, 1997).

## SUMMARY FINDINGS

Before describing the collective lessons of our industry studies, the Board concedes that it is incomplete and may be misleading to compare all but the newest industries' performance over two or three decades rather than across generations and across countries. From the Landau and Arora account of the American, German, British and Japanese chemical industries since the mid-nineteenth century it is apparent that competitive advantage has shifted from time to time from one country to another and short-term strong or weak performance does not necessarily signify a long-term trend unless basic structural conditions remain the same.

First, history matters. Wars and economic upheavals have unpredictable but long-lasting effects. During the decades after the second world war, the U.S. chemical industry grew at twice the growth rate of the economy as a whole. It thus contributed to growth at the macroeconomic level, a role recently assumed by the information industries. This was only partly the result of the destruction of much of the German and Japanese industries and the damage inflicted upon the British. To a greater degree it was attributable to robust innovation, especially in petrochemicals technology.

Second, the size of the national market and the national political and social environment matter. In a peaceful world where natural resources can be shipped around the world, know-how and economies of scale can be decisive factors in maintaining competitive advantages. The "environment" encompasses a complex mix of institutions and policies, not only government macro- and microeconomic policies but also durable national institutions. These include university systems both performing research and training scientists and engineers, legal systems protecting property (including intellectual) and promoting competi-

**Gaining and Losing Advantage in the Chemical Industry: The Dynamics of Long-Term Growth**

A historical survey of the chemical industry shows that competitive strength in the long run as well as in the short run rests on a robust institutional infrastructure and supportive government policies that are general rather than highly sector-specific in their focus and intent. A well-functioning, growing economy depends on

- a complex mix of institutions and policies that extend beyond the legal system and fiscal and monetary policies to include such items as national systems of higher education, regulation, and trade policy;
- market-based policies that support the interaction of social institutions and policies to generate high economic growth within a relatively stable, predictable, macroeconomic environment that favors investment; and
- the size of the market, its historical development, and the political and social environment of the country in question.

A long-term view highlights the central importance of technological innovation for the growth of the chemical industry and for industrial societies as a whole. But technological innovation must be defined to include the broader constellation of risk-taking activities entailed in commercializing the technology and underlying science subject to the influence of economic policies and social institutions such as national research and teaching institutions. Compared to these conditions, targeted government science and technology policies do not matter very much.

—Ralph Landau, Stanford University and Ashish Arora, Carnegie Mellon University tion, labor markets, capital markets and institutions transferring capital from savers to investors and allocating it among competing firms and governments, and corporate governance systems providing incentives to managers for investment and risk-taking and dividing profits between owners of companies and other stakeholders. None of these factors is fixed; all of them are changing but at various rates. A factor that may serve a country's industries well at one time may not at another. An example is Japan's low cost of capital, contributing first to an investment boom and then a bust.

Third, technological innovation matters, but in the broad context of human capital development and commercialization and diffusion of know-how, not simply research and invention.

With the benefit of this perspective, it becomes more feasible to summarize the findings of the other 10 commissioned industry studies, limited as they are to a period of only a few decades, primarily from an American point of view. Even though more or less enduring national system differences do not figure prominently in these explanations of industries' improved performance, the two perspectives are quite complementary. Competitive strength in the long run rests on a robust institutional infrastructure and a stable, predictable macroeconomic environment rather than on policies that are targeted on particular industries and firms.

The industries that the Board examined exhibit enormous diversity in structure. Some, such as chemicals, are highly concentrated, with a small number of global firms dominating international trade, capital investment, and R&D spending. Others, such as powder metallurgy and apparel, are populated by small firms with modest technical capabilities. In semiconductors, pharmaceuticals, computer software, and computer peripheral equipment, large and small firms appear to complement each other and sometimes collaborate. Food retailing, trucking, and banking exhibit some regionally based concentrations of small and medium-sized firms but also an increasing number of large national and international enterprises.

The structure of very few industries has remained stable in the past 20 years. In several cases leading firms have been displaced by second-tier firms or even new entrants. In other cases considerable consolidation has occurred. These structural changes are just the tip of the enormous "churning" that has affected regions of the country, customers and suppliers, and, of course, workers, often adversely. This churning has taken a variety of forms—employment downsizing by major companies, shifts in the location of operations both within the United States and abroad, and changing the skill requirements of many jobs, leaving many workers with minimal basic skills and unable to meet required competence levels.[2]

[2]See pp. 49–50.

Although many people have not benefited, restructuring combined with continuous innovation, especially by smaller newer firms, has been accompanied by a steady decline in the unemployment rate in this country to levels not seen in decades. Moreover, the overall picture presented by the industry studies is one of stronger performance, both in mature lines of business and through proliferation of new products, processes, and services. Not all studies used the same measures of performance but frequently cited quantitative and qualitative indicators of improvement include increased market share, usually global market share vis-à-vis foreign-based producers and suppliers; growth in output; growth in productivity, sometimes measured as traditional labor or total factor productivity, but often framed in terms of industry-specific measures of productivity; and opening markets for new products and services.

Some preeminent U.S. industries, among them computers, pharmaceuticals, and chemicals, remain in world leadership positions although challenged by foreign competition. That does not necessarily signify stability and continuity. In most cases it means that U.S.-based firms, some but not all of them industry leaders in the 1980s, have capitalized successfully on innovation processes that have changed radically or are in the process of changing. In contrast to suppliers of other peripheral equipment and electronic components, U.S. hard disk drive producers have steadily increased their world market share by linking U.S.-based technical and design resources to low-cost efficient Asian production.

Another high-technology industry, semiconductors, has recovered from competitive decline, regaining its formerly dominant market share, apparently through a combination of product specialization and manufacturing process improvement. The steel industry has also recovered from a low point in the early 1980s.

Perhaps the most surprising cases, the powder metallurgy parts and apparel industries, have held on, even accommodating new entrants, through a combination of process improvements and responsiveness to customers. The recovery of the automobile industry has contributed to the relative prosperity of steel manufacturers and metal parts suppliers—just one example of a virtuous cycle of growth.

Finally, the banking, trucking, and food retailing industries are being transformed, primarily by the lowering of regulatory barriers to expanding product lines and geographic scope and by the incorporation of information technologies enabling the design and delivery of new services. But in these cases innovation has also been driven by domestic competitors nominally outside the industries—nonbank financial service companies (insurers, brokerages, etc.), railroads and airlines, and the ubiquitous Wal-Mart and warehouse stores.

## SOURCES OF STRONGER PERFORMANCE

Landau, Taylor, and Wright (1996) have argued that to explain shifting patterns of industrial performance across nations, it is essential to systematically

**Product Specialization and Process Improvement in the Semiconductor Industry**

The performance of the U.S. semiconductor industry during the 1980-1997 period reflected shifts in both product and process technology management. In contrast with the Japanese firms that during the mid-1980s appeared to pose a serious competitive threat, U.S. firms proved to be relatively agile in repositioning their product portfolios to emphasize new products that were relatively design intensive. At the same time, however, U.S. firms improved their manufacturing performance, which enabled them to exploit their long-standing strengths in product innovation more effectively. From a position of substantial inferiority in the development and management of semiconductor process technologies in the early 1980s, U.S. chipmakers narrowed the gap between U.S. and Japanese manufacturing capability and productivity in some product lines by the end of the decade.

Both repositioning and improved manufacturing performance almost certainly were necessary; neither was sufficient. Improvements in both of these dimensions of performance reflected improved technology management practices, where these practices are defined to include management of process technologies on the shop floor as well as improvements in the development and adoption of new process and product technologies. In addition to these changes in their internal management of innovation and production, U.S. firms expanded collaboration among one another, with equipment firms, and with non-U.S. firms. Finally, the entry of specialized design firms into the U.S. semiconductor industry signaled the development of new approaches to the organization of the innovation process that involved greater reliance on specialization and arms-length arrangements.

—Jeffrey Macher, David Mowery, and David Hodges, University of California at Berkeley

examine the context in which firms operate, starting at the most general national characteristics of industrial countries and proceeding through various levels of governmental, institutional and social factors, and macroeconomic and microeconomic policies to the characteristics of particular industries and firms. The synthesis here follows this analytical framework, termed "levels of comparative advantage," which represent higher and lower levels of aggregation (see Table 2).

**TABLE 2** Levels of Comparative Advantage

| | |
|---|---|
| National Governance | |
| Socio-Political Cimate | |
| Macro Policies | |
| | Fiscal |
| | Monetary |
| | Trade |
| | Tax |
| Institutional Setting | |
| | Financial |
| | Legal (including torts, antitrust, and intellectual property) |
| | Corporate governance |
| | Professional bodies |
| | Intermediating institutions |
| Structural and Supportive Policies | |
| | Education (including university-industry relations) |
| | Labor |
| | Tax |
| | Science and technology (including role of engineers and scientists) |
| | Regulatory and environmental |
| The Industry Collectively | |
| Companies Within the Industry | |

### A Virtuous Cycle of Growth in the Powder Metallurgy Parts Industry

The $1.8 billion North American powder metallurgy parts industry currently includes approximately 213 companies competing at various levels in the manufacture of P/M structural parts, powder forging, bearings, friction materials, and metal injection molded products. More than two-thirds of part sales are automotive applications, the most significant growth segment since 1980. The industry has responded to several years of real growth that, while currently moderating, is expected to continue. While some managers and analysts have suggested less reliance on automotive parts, these parts continue to exhibit strong growth as auto producers continue to use new P/M applications at the same rate as the industry diversifies into new applications. They are attractive for parts

*continues*

producers because of the large volumes that come with a successful contract. Automotive applications have increased from 15 pounds per U.S.-made auto/light truck in 1988 to 29.5 pounds in 1996. Recent forecasts suggest that this volume will increase to 32.5 pounds in 1998.

Auto company captive P/M plants became the first large-scale P/M operations, but they began to increase their outsourcing during the 1970s, and many of the P/M divisions were divested during the 1980s. This did not change the P/M industry's dependence on the automobile, but it caused major changes in the supply chain and in the industry's pattern of technological innovation and economic performance during the early 1970s. This period saw the auto industry, and thereby the P/M industry, struggle through the energy crisis and the onslaught of foreign competition, "auto transplants" (domestic production facilities of foreign owned auto producers), and auto imports. Earlier strong demands and tight powder supply were followed during this period by falling P/M part sales and even auto industry restrictions on new P/M parts developments.

Current P/M industry prosperity is based on the success of auto industry restructuring. Longer production runs, lower cost energy and labor, and cost reduction programs initiated by suppliers in response to automotive customers, have made the North American P/M industry the most competitive in the world, with a cost advantage in 1996 of about 20–30 percent over Japanese parts producers. Strengthening of the dollar since then has reduced this advantage, but competition with overseas firms has yet to become a major issue in the North American P/M industry.

Powder metallurgy has thus played a very substantial role in re-engineering powertrain components and has successfully converted other engine parts. This success, in turn, continues to drive P/M growth for automotive and other customers. Much technical innovation in applications originates in the U.S. auto industry with its ongoing acceptance of P/M as a solution in their search for more cost effective net shape manufacturing technologies.

—Diran Appelian, J. Healy, P. U. Gummeson, and C. Kasouf, Worcester Polytechnic Institute

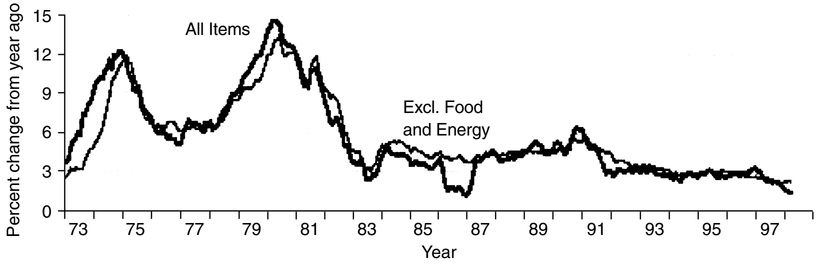


**FIGURE 1** Consumer price index (percent change from year ago).
Source: Federal Reserve Bank of St. Louis (1998).

## Stable and Supportive Macroeconomic Policies

A clear difference between the period of apparent decline of U.S. industrial competitiveness in the 1980s and the current period of sustained growth is the macroeconomic policy environment—the collection of actions taken by government to keep inflation low and business cycle fluctuations in output and employment small. Macroeconomic policy includes both monetary policy and fiscal policy. It also includes exchange rate policy and the coordination of national macroeconomic policies that affect international transactions.

Figures 1 through 7 show a strong correlation between a combination of steady and conservative fiscal policy emphasizing federal budget deficit reduction and cautious monetary policy emphasizing stabilization and low domestic inflation, interest, and exchange rates since the late 1980s.

Note that for the past several years not only have inflation and interest rates and the value of the dollar been low compared to their levels for much of the 1980s, but they have also been quite stable, avoiding for the most part the sharp ups and downs that characterized even the 1960s and 1970s. Instability in these market factors tends to discourage investment, which contributes to growth.[3]

Not surprisingly, this favorable combination of circumstances appears to have been beneficial to output and exports, and to a lesser extent, investment. Bernard and Jensen (1998) examined various explanations for the U.S. export boom in the 1990s and concluded that depreciation of the dollar coupled with increases in foreign income accounts were largely responsible.

Improved productivity—the key to rising real income and increased industrial competitiveness—is less easy to discern. As is well known, in the early 1970s, productivity slowed dramatically across the entire industrial world and has not since achieved the rates recorded in the 1950s and 1960s. The reasons for this

[3]For a discussion of the relationship between short-term macroeconomic stabilization policy and long-term economic growth, see Taylor, 1998.

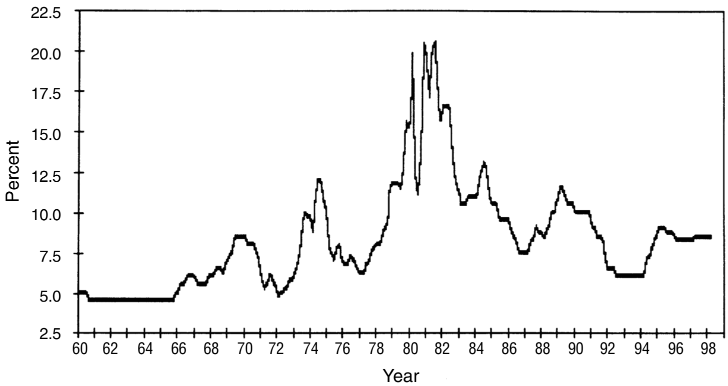


**FIGURE 2** Bank prime loan rate (%).
Source: Bos (1998).

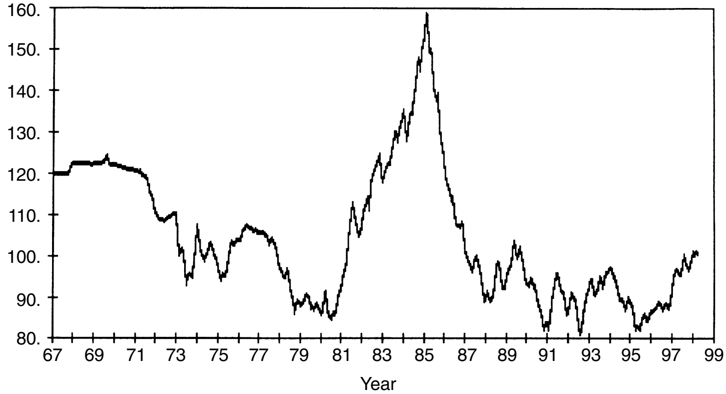


**FIGURE 3** Trade-weighted exchange index of the U.S. dollar.
Source: Bos (1998).

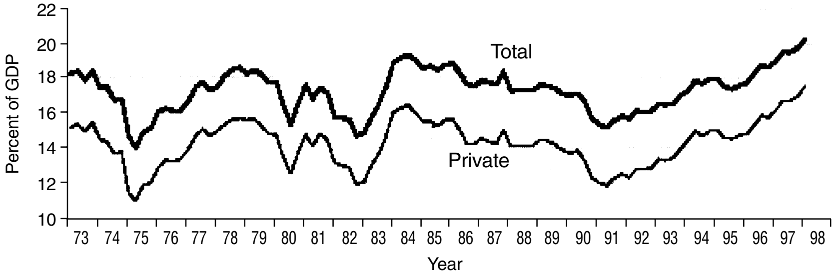


**FIGURE 4** Real investment (percent of the GDP).
Source: Federal Reserve Bank of St. Louis (1998).

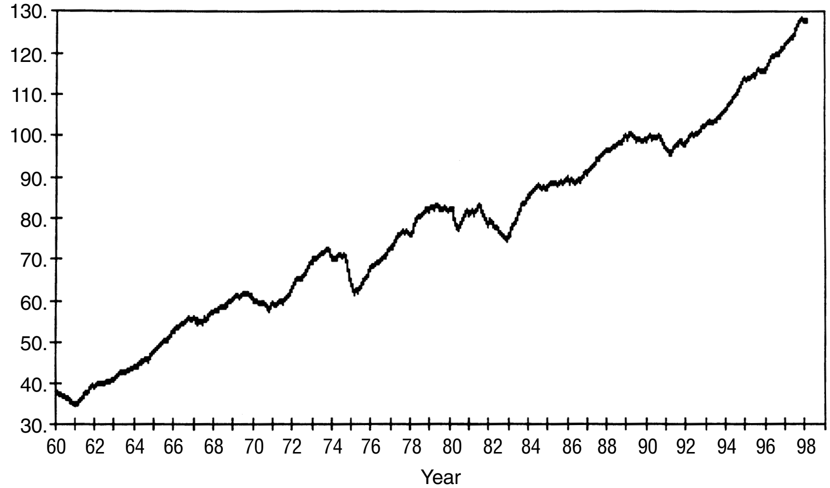


**FIGURE 5** Industrial production.
Source: Bos (1998).

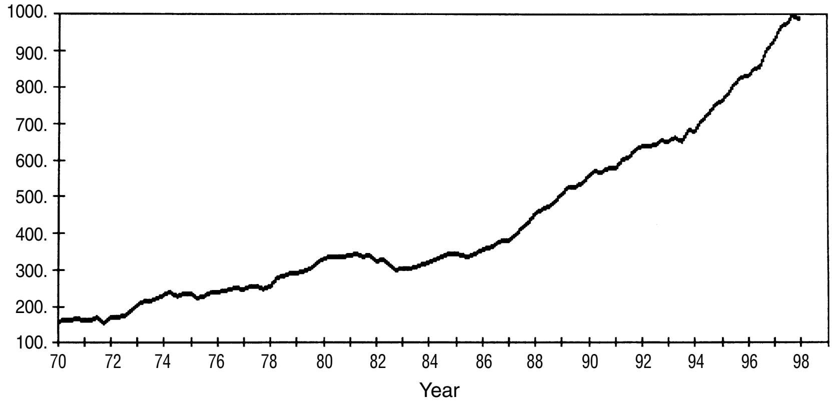


**FIGURE 6** NIPA-real exports-chain weighted[4] (billions of 1992 dollars).
Source: Bos (1998).

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[4]The chain weighted procedure uses each year and the preceding year as a basis for computing growth rates. It thus eliminates the problems associated with using a fixed base year.

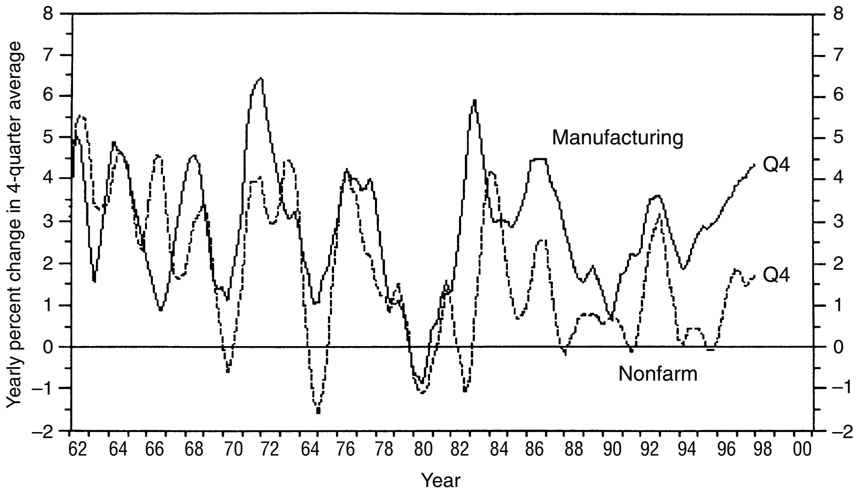


**FIGURE 7** Productivity (yearly percent change in four-quarter average). Source: Yardeni (1998).

slowdown have been analyzed and debated extensively and still are not a matter of consensus among economists. What is generally accepted is that in the 1990s U.S. productivity growth in the manufacturing sector, where output is easier to measure, accelerated, albeit not to pre-1970 levels, along with improvements in other economic indicators. In the now-dominant service industries, no significant improvement is discernible despite large investments in presumably efficiency-enhancing information technologies, but that may be a function of inadequate measures of output and overreliance on aggregate data (The Conference Board, 1998).

A growing body of empirical evidence at the establishment or firm level, much of it presented to a STEP-sponsored international research conference in 1995[5] confirms that adoption of new process technologies, especially when preceded or accompanied by worker training and managerial improvements, has spurred productivity growth in many industries. Many of these information technologies have also supported development of new products and the appearance of new services, especially in the service industries. The only thing that aggregate data measure more poorly than improvements are the efficiency and quality of existing services.

[5]Conference on the Effects of Technology and Innovation on Firm Performance and Employment, May 1–2, 1995. Papers from the conference appear in *The Journal of the Economics of Innovation and New Technology*, vol. 5, pp. 99–343, 1998.

## Favorable Microeconomic Policies

Macroeocnomic policy is not the only arena in which the U.S. government, frequently criticized for politically expedient economic policy vacillation within as well as between administrations, steered a steady policy course in the 1980s and 1990s with important consequences for innovation and performance in a number of industrial sectors. The following microeconomic policies also exhibit a high degree of consistency.

### *Economic Deregulation*

Beginning with the airlines in 1978, successive administrations and congresses have scaled back government control of exit and entry and services and prices in a series of major industrial sectors: trucking, railroads, energy/natural gas. And the process of deregulation is progressing in telecommunications, electric power, and banking.

Deregulation is enormously disruptive of established industry structures and has contributed significantly to the "churning" phenomenon that has characterized the economy over the past two decades, with both positive and negative consequences. Moreover, the effects tend to ripple out well beyond the deregulated sector. For example, trucking deregulation has affected food retailing; and the ongoing restructuring of the U.S. telecommunications industry encourages the entry and growth of firms providing specialized hardware, software, and networking to manufacturing and service industries of all sorts. The benefit of deregulation is to open up new market opportunities and release competitive pressures on established and new firms to exploit them. This appears to be a relatively slow process, however, with deregulated firms growing in efficiency only gradually. The good news for economic performance is that the benefits of deregulation are not a one-shot occurrence but extend over a period of time (Winston, 1998).

### *Antitrust Enforcement*

In antitrust policy the Reagan, Bush, and Clinton administrations adopted a substantially more lenient enforcement posture than their predecessors, apparently convinced by the argument that vigorous pursuit of limitations on domestic market power could impede U.S. firms in international competition. Justice Department guidelines and review procedures for mergers were relaxed somewhat, and major suits against some high-technology firms were settled or dropped in the early 1980s. In 1984 the White House also supported legislation, the National Cooperative Research Act, limiting antitrust penalties for collaboration among firms in precommercial research. Subsequent amendments extended the same treatment to some cooperative production activities. As a result of the generally permissive policy, the entries and exits, mergers and acquisitions, and co-operative ventures that characterized the restructuring of many industrial sectors in the 1980s and 1990s were largely unimpeded. Of course, the ongoing antitrust action against Microsoft and the recently settled Federal Trade Commission proceeding against Intel signal strong concerns on the part of antitrust officials about competition in the information technology sector.

*Intellectual Property Protection*

Beginning in 1980, a series of legislative actions, judicial decisions, executive branch initiatives, and international agreements spearheaded by the United States ostensibly strengthened the rights of intellectual property owners and extended IPRs into new areas of technology.[6]

- The Bayh-Dole Patent and Trademark Amendments Act of 1980 enabled universities, other nonprofit organizations, and small businesses to acquire exclusive rights to inventions developed with federal support. In 1984 some restrictions on the kinds of inventions that universities could own were removed. Gradually, this policy was extended to federal contractors and research grantees, regardless of size in most circumstances, eventually reversing the previous pattern of federal agency assumption of patent rights and nonexclusive licensing.
- In *Diamond v Chakrabarty* (1980) the Supreme Court allowed patenting of organisms with artificially engineered genetic characteristics. Subsequently, the Patent and Trademark Office granted innumerable biotechnology product and process patents.
- In 1982 Congress established the Federal Circuit Court of Appeals to handle patent litigation appeals, limiting the wide variation in circuit appeals courts' treatment of patent infringement cases and generally strengthening the position of patent holders.
- The 1984 Hatch-Waxman Act extended the patent terms on regulated pharmaceuticals.
- The Semiconductor Chip Protection Act of 1984 established a sui generis mode of protecting the design or mask work used in semiconductor manufacturing—a form of protection combining elements of patents and copyrights with elements of unfair trade competition and trade secrecy law. Semiconductor firms' reliance on traditional patents and trade secret protection has also increased.

[6]The characterization of these steps as strengthening intellectual property protection does not mean that they were uniformly supported by individuals and firms relying on intellectual property rights. Frequently, there have been differences between individual inventors and firms, between large and small firms, and among industries.

- The 1988 Process Patent Amendments Act enabled U.S. process patent holders to block the import of foreign products produced by methods infringing their patents.
- The U.S.-spearheaded multilateral negotiations under the auspices of the GATT Uruguay Round resulted in the 1994 TRIPS (Trade-Related Aspects of Intellectual Property Rights) Agreement, setting minimum standards of IPR protection and enforceability among World Trade Organization members and requiring protection of certain integrated circuit designs, plants and microorganisms, and trade secrets. At the same time, the U.S. government pursued stronger IPR protection in a series of bilateral venues.
- The 1996 Economic Espionage Act, a law primarily aimed at foreign industrial espionage for the first time subjected domestic trade secret theft to federal civil and criminal penalties. Formerly, trade secrets were protected only by state laws.
- The 1998 State Street Bank decision of the Federal Circuit Court of Appeals upheld the patentability of business application software.

Perhaps with the exception of the biotechnology industry, where new firms with strong patent positions find it easier to attract financing and large established pharmaceutical firms depend on intellectual property protection to protect their enormous up-front drug development investments, the effects of strong IPR protection are far from clear. Overall, there has been an increase in patenting, suggesting that firms are able to appropriate more of their technology investments. At the same time, the costs of protecting IPRs in litigation are high, suggesting that the main beneficiaries of strong IPRs are established firms. Recent research presented at an April 1998 Stanford University workshop on intellectual property and industry competitive standards suggests that patenting motivations, and hence strategies, differ systematically among industries and across countries (Headley, 1998; Cohen et al., 1998).

*Trade Liberalization*

In two successive multilateral trade negotiations and a host of bilateral settings, some of them focused on particular industries, products, or technologies, the United States has pursued a reduction in tariffs and nontariff barriers and a recognition that a variety of public policies heretofore considered to be of domestic interest only—R&D supports, competition policy, and IPR policies—have discriminatory trade effects and ought to be subject to international rules. Successive administrations have also resisted limitations on foreign investment and avoided the kinds of import limitations previously used on foreign steel, automobiles, and other products.

*Research Support*

The federal government's support of academic research in all major scientific and engineering fields as well as its substantial support for training scientists and engineers via fellowships, traineeships, and research project funding is perhaps the postwar microeconomic policy with the longest duration and continuous political support, until recently fluctuating only at the margin and to some extent in its composition because of the dependence of some research fields on mission agencies with changing requirements and fluctuating budgets. Federal support of research by all performers in most research fields continued to increase in real terms through the 1990s in a few research fields. In others, mainly physical science and engineering fields, federal support peaked in 1992 or 1993 and continued to decline until 1997, the last year for which actual funding obligations by research field are known. The implications are discussed below, and the data are presented in Appendix A. Of course, the effects of the reduction in research funding will not be discernable for several years, if then.

*Other Policies*

Not all public policies have exhibited consistency over the past decade-and-a-half. The taxation of capital has been especially erratic over a long period—for example, with regard to the neutrality of the tax system. With the exception of the Tax Reform Act of 1986, the tax system has strongly favored certain kinds of investments over others, with some biases changing dramatically from one tax bill to another.

The evidence presented at the STEP Board's conference on international tax policy is that U.S. tax rules governing foreign income and expense allocations of U.S.-based corporations and the tax treatment of corporate R&D have important economic consequences through their influence on the levels and location of research and innovation and capital investments of multinational companies that account for most of the R&D performed in and most of the goods and services exported from the United States. Yet these policies have been subject to the vagaries of the federal budget and partisan politics. For example, since its first introduction in 1981, the research experimentation tax credit has expired and been renewed nine times, occasionally after lapsing entirely and from time to time in a slightly different form that the one previously in effect (Nadiri and Mamuneas, 1997).

In one respect there has been greater consistency in federal tax policy. The Tax Reform Act of 1986 lowered the federal statutory corporate income tax rate from 46 to 34 percent, and it has remained near that level since, making the United States, initially at least, a relatively low tax country. Similarly, the statutory tax rate on capital gains has been reduced.

Coordinated, targeted policies supporting particular industrial sectors have been rare, in contrast to the amount of debate that took place in the 1980s and early 1990s about the wisdom of such policies. There have been several instances of protection against competing imports—steel and apparel, for example—but among the industries examined, the semiconductor industry represents the only case of multiple government interventions. These included support of manufacturing technology development and diffusion, action against foreign dumping, and assistance in foreign market penetration. The authors of the STEP semiconductor study attribute some but not most of the industry's turnaround to these policies (Mowery, ed., 1999). In contrast, a number of state as well as federal programs to support precompetitive technology development have been untargeted but also modestly funded and often short lived. Not surprisingly, their effects have been diffuse.

In explaining U.S. industries' performance, the STEP case studies do not yield firm conclusions about the relative contributions of particular macro- and microeconomic policies. Their influence, undoubtedly, has varied over time and from industry to industry. All in all, however, the U.S. policy environment in this period has been supportive of industrial growth. Indeed, it approximated the most frequent prescriptions for recovery in the 1980s. For example, DRI opined in 1984 that the steps to promote a "healthier development of U.S. manufacturing" should include lowering interest rates, exchange rates, and the cost of capital through budget deficit reduction and capital market liberalization; opening up world markets through more aggressive trade policies; stable monetary and fiscal policies, to avoid the cyclical pattern of the postwar period and to encourage long-term investment; support of basic research and training, including support of cooperative research projects to meet world competition; and regulatory and tax policies that favor industrial development (Eckstein et al., 1984).

## Industry and Firm Strategies

The public policy environment, however favorable to innovation and growth, has not dictated the variety of ways—some familiar, others more subtle, and not all of them successful—in which U.S. companies and industries went about responding to domestic and foreign competition, new market opportunities, and technological change. The 11 industries that the Board examined pursued one or a combination of the following strategies, with at least some near-term improvement in performance.

### *Specialization*

In a number of industries, U.S. firms have restructured their product lines rather than continue competing head to head with Japanese firms in established lines of business. U.S. semiconductor producers, for example, exited from the memory chip market, focusing instead on microprocessors and customized devices where innovative design capacity conferred an advantage. As expected, these turned out to be the fastest-growing markets and, unlike the memory device market, did not readily attract new country entrants such as Korea.

*Consolidation*

A high rate of merger and acquisition activity characterized several industries in the 1980s and 1990s, not always with beneficial results. The case study of banking concludes that much of the consolidation as well as much of the industry's investment in information technologies initially diminished rather than increased stock market values.

*Internationalization*

Nearly all industries, even trucking and food retailing, increased their international activities in one way or another, or by using a combination of strategies—exports, mergers, alliances, and foreign investment—but rarely by large-scale movement of production offshore. An exception was the U.S. hard disk drive industry, which continued to compete head-to-head with Japanese and European producers, successfully increasing its global market share, by locating production of current-generation products in Singapore and older products elsewhere in Asia. Design and R&D functions did not follow, however, but have remained largely in the United States. Indeed superior management of geographically dispersed operations—R&D, production, and distribution—appears to be a comparative advantage of the U.S. industry.

**Globalization in the Hard Disk Drive Industry**

One important ingredient [in American dominance in the disk drive industry] has been the globalization of assembly. Innovation is critical, but companies have to be equally effective at transferring new products quickly into volume production while keeping costs down in the face of rapid price erosion. The president of Seagate, the world's largest disk drive company, says that his company is happy to be a follower rather than an innovator but to *outproduce* its competitors. The centerpiece of this production strategy has been overseas assembly.

*continues*

In general, American firms have not been known for their manufacturing prowess. Yet U.S. disk drive companies have demonstrated that this generalization does not hold for all industries. American disk drive companies competed squarely in and came to dominate the low-margin, high-volume segments—the price and capacity points most in demand by users of personal computers. Judged by what scholars have had to say about the manufacturing failures of American firms in other industries, this is an extraordinary accomplishment. American industry achieved it primarily by being the first as a group to shift assembly offshore to lower-cost locations, where it quickly constituted an entire value chain of activities. If Silicon Valley is the geographical synonym for innovation, then non-Japan East Asia has come to signify low-cost assembly and logistics management...

In 1982 and 1983 Seagate, Computer Memories, Ampex, and Tandon, all independent producers, became the first companies to move HDD assembly to locations for reasons other than access to host country markets. These firms began to assemble drives in what they saw as the best location from a cost standpoint, selecting low-wage areas in Asia, particularly Singapore...

By 1990 Singapore was the world's largest producer of HDDs, accounting for 55 percent of global output, measured in shipments, with the rest of Southeast Asia accounting for only a percentage point more...

The revealed global strategies of American and Japanese firms could not have been more different. By 1990, eight years after the first HDD was produced in Singapore, American firms assembled two-thirds of their disk drives in Southeast Asia. What began as a variation from the norm became a collective phenomenon. In contrast, Japanese companies assembled almost none in Southeast Asia, and only 2 percent in the rest of Asia. Japanese companies instead continued to manufacture predominantly in Japan, where they produced 95 percent of their disk drives...

Eventually the success of the American firms impelled the Japanese to follow with investments in Southeast Asia. Between 1991, when Fujitsu began production in Thailand, and 1996, all the principal Japanese HDD firms gradually shifted manufacturing to Southeast Asia, principally the Philippines.

—David McKendrick, University of California at San Diego

*Manufacturing Improvement and Cost Reduction*

Several industries focused on reducing costs and improving productivity and quality in the manufacturing process. In the case of semiconductors, this yielded substantial gains, not only for producers but also for the struggling U.S. semiconductor equipment industry, although not surpassing the yield rates of Japanese semiconductor manufacturers.

**Systems Integration Innovation in the Banking Industry**

...Most retail banks do not have something called an R&D group. If they do, these groups play an important, but small role in the overall innovation practices of the organizations. Marketing, business units, information technology, and a complex web of information technology suppliers and consultants drive the innovation processes in banking.

Consider the case of National Bank, where there was no division devoted to thinking about or implementing innovation, no "research and development" or similar functional structure. Rather, pressure for innovation built incrementally as a result of numerous smaller initiatives by marketing, by those responsible for managing technological systems, and by line managers. Each area felt competitive pressure and began to develop responses. At National Bank, these responses were eventually, to some extent, collected and channeled through the implementation team, although they also maintained some momentum of their own.

At National Bank, translating this pressure to innovate into actual technological and organizational changes was greatly facilitated by the continuing presence of consultants and of suppliers of technology. Indeed, one way to understand at least part of the role of consultants is that they function as suppliers of the organizational technology required to leverage the potential gains from innovations in computing and telecommunications systems. While the organization continues to develop its capacity to learn and innovate, it explicitly recognizes that it has considerable distance to travel in order to exercise this capacity more independently.

One further lesson we take from National in the midst of this redesign is that changes in IT, and in technological capabilities can spark the desire for system-wide innovation and even shape its particular form. With

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the enthusiastic promotion of consultants and outside vendors, technology is perceived by retail banks to be a catalyst for change across the organization. Yet even where this technology is over-sold, poorly understood, or fails to deliver on its promises, the process of innovation may take on its own momentum.

—Frances Frei, Harvard University, and Patrick Harker and Larry Hunter, University of Pennsylvania

*Strategic Repositioning*

Probably most important, firms in several U.S. industries have shown a remarkable ability to introduce new products and processes, capitalizing on shifts in demand to create new markets, often through the deployment of technologies new to those industries, as well as to accomplish cost reduction and quality improvement. In many cases this pattern has been associated with new entrants (e.g., specialty chemical firms, "fabless" semiconductor design firms that contract out their manufacturing, package express carriers, and steel minimills) or with intermediary firms supplying information technology and engineering services (e.g., consulting and accounting firms, software producers, systems integrators, logistics suppliers).

**Specialized Engineering Firms in the Chemical Industry**

The rise of [large-scale chemical production] involved a new division of labor and involved a new type of firm—specialized process design and engineering contractors, hereafter the SEFs. In addition to supplying proprietary processes, some SEFs also acted as licensers on behalf of chemical firms and provided design and engineering know-how. During the past ten or fifteen years, SEFs may have declined in importance but in the post-World War II period as a whole they have played an important role in developing new and improved processes and a crucial one in diffusing new technologies.

As one might expect, given the comparative emphasis on large-scale production, the United States enjoyed an early lead in chemical engi-

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neering of plants. The first SEFs were formed in the early part of this century, and their clients were typically oil companies. Prominent among the early SEFs are companies such as Kellogg, Badger, Stone and Webster, UOP, and Scientific Design...

Initially European and Japanese firms, and later firms in the Middle East and East Asia, benefited greatly from the technology transfer by the SEFs. Between 1960 and 1990 roughly three-fourths of the petrochemical plants built all over the world were engineered by SEFs. By providing technology licenses to firms the world over, SEFs played a major role in the diffusion of chemical, especially petrochemical, technologies. As independent developers of technology, SEFs were similar in some respects to today's biotechnology companies, often partnering with several different chemical firms in developing new technologies...

Thus, a major consequence of SEFs was, paradoxically enough, to reduce the strategic importance of process technology, in essence by helping to develop and supply a market for technology. The large number of potential licensees and the possibility of competing innovation made it difficult for a chemical firm to gain long-term advantage from a single innovation. Only by continual improvements and innovation could a company hope to derive a long-term advantage, and in some cases even that was not sufficient.

In addition to inducing entry and creating competition on a global scale, the development of a market in technology licenses brought to the fore the importance of other factors influencing competitive success—availability of raw materials and capital, proximity to market, and other idiosyncratic factors such as severity of environmental regulation and macroeconomic instability. The important point is that although initially the benefits of the division of labor between chemical producers and SEFs accrued to U.S. chemical firms, over time these benefits became available to chemical producers in other countries as well. The very factors that underpin the U.S. success also enabled other countries to catch up.

—Ashish Arora, Carnegie Mellon University, and Alfonso Gambardella, University of Urbino

The largest trucking companies first purchased logistics services and later established subsidiaries to provide them to other transportation firms.

### Customer Needs and Logistics Innovations in the Trucking Industry

Globalization, technology, and specialization have combined to bring a new dimension to the trucking industry: logistics. Logistics can be defined as a concept to guide economic processes and as a tool of rationalization to optimize purchasing, transport, reshipment, and warehousing. Logistics uses the right information to move materials to the right place, at the right time, for the right cost. While logistics once belonged in the realm of the manufacturing firm, today trucking firms are seizing the initiative and absorbing the logistics function into their value chains.

As customers focus on cutting costs and developing core competencies, trucking firms are restructuring to offer the total transportation solution by including logistics and a variety of other transportation options in their corporate portfolio. The logistics business, almost nonexistent ten years ago, is now approximately a $20-30 billion industry segment and is projected to grow at about 20 percent a year.

Logistics may not only provide functionally and lower costs to the customer; it may also improve service and increase the customer's perception of value. This is especially true because many customers are focusing on ways to reduce costs and improve quality in response to international competition. Consequently, many U.S. businesses are steadily reducing their investment in inventory. Manufacturers are also faced with the need to reduce cycle time...

The availability of appropriate technology has facilitated the growth of logistics...Logistics providers are using large databases, complex software and algorithms, supporting hardware, and the latest trucking and communication technologies to track fleets, organize customers and loads, and provide the most efficient way to satisfy the customer...

Firms have used different organizational arrangements to incorporate logistics in their arsenal. Schneider, the nation's largest TL firm, is associated with logistics provider, Schneider Logistics. The logistics arm of Schneider innovates and develops products to enable Schneider to compete effectively and efficiently. In contrast, J.B. Hunt, another TL firm and a close competitor of Schneider, has a logistics arm, a wholly owned subsidiary call Hunt Logistics, which provides independent logistics services...

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Smaller firms specializing in logistics are usually organizing in one or two ways: either as dedicated contract carriers or as not-asset based supply chain management companies...

Logistics and supply chain management have brought about some restructuring of the trucking industry. Firms are now offering a variety of transportation services including TL, LTL, logistics, package express, and intermodal as one-stop transportation solution. They are accomplishing the feat of "one call, one carrier" primarily through acquisitions, mergers, and alliances.

—Anuradha Nagarajan, James Bander, Harish Krishnan, and Chelsea White, III, University of Michigan

*Changing Sources of Innovation*

In computers, pharmaceuticals, and perhaps chemicals, innovation processes have changed radically, and U.S.-based firms, not necessarily the industry leaders of a decade or two ago, have capitalized on the shift to achieve a strong competitive advantage. Bresnahan describes how in the computer industry a "Silicon Valley" system of organizing innovations—multiple innovative companies excelling in components, hardware, software, networking, and other specialized parts of the industry—replaced the integrated, hierarchical, more self-contained "IBM" system of innovation.

**U.S. Competitive Advantage in Computing**

With [so much] change, it is natural to ask what has led to the long persistence of U.S. dominance in the industry. Some factors favoring American competitiveness *persisted over time*. First among these is the large size and rapid growth of the American market. Some of the growth is related to the U.S. macroeconomy; the rest is related to education in computer technologies and a highly skilled labor force in information technology. U.S. tax, antitrust, and legal policy has not been supportive of computing, but it has not been dangerously hostile either. U.S. universities, always a source of entrepreneurship, have been highly receptive to

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the launching of new scientific fields and academic curricula. Finally, there is the tendency for dominant firms and technologies to persist for a long time within the industry's established segments.

Other sources of American competitive advantages have been *changing over time*. In mainframes, for example, the major sources of American advantage were linked to *a single firm's advantages*; IBM presented a unique commitment to R&D policies and to the Chandlerian three-pronged investments in management, production, and marketing. No other firm in the world was able to match IBM's capabilities and investments. In mini- and microcomputers, U.S. advantages were related to *favorable entry and growth conditions* for new firms in new market segments and to the creation of open multifirm platforms that created local knowledge externalities. In computer networks, U.S. advantages are related to the presence of *local knowledge externalities* and strong complementarities between various components of the multiform standard platform. The creation of each of these new segments involved very substantial entry opportunities for new firms...

The geographic location of the competencies supporting American success has several times shifted within this large country. In mainframes, American advantages were related to the areas of IBM location of R&D and production, centered in New York but widely dispersed. For minicomputers, the sources of competitive advantages were mainly centered with the eastern part of the United States, with important exceptions such as Hewlett Packard. In microcomputing, and even more so in computer networks, there has been a regional shift from areas in the eastern part of the United States westward toward Silicon Valley...

Perhaps the most important advantage, however, has been the flexibility of the U.S. computing industry—its ability to abandon old competencies in favor of new ones.

—Timothy Bresnahan, Stanford University

In pharmaceuticals, the revolution in molecular biology was exploited as a production tool by small biotechnology start-up firms and as a research and drug discovery tool by the large established pharmaceutical producers.

## Science-Based Innovation in the Pharmaceuticals Industry

The transition from random to guided drug discovery required the development of a large body of new knowledge and substantially new organizational capabilities in drug research. So-called random drug discovery drew on two core disciplines—medicinal chemistry and pharmacology. Successful firms employed battalions of skilled synthetic chemists and pharmacologists who managed smoothly running, large scale screening operations. Although a working knowledge of current biomedical research might prove useful as a source of ideas about possible compounds to test or alternative screens to try, by and large firms did not need to employ researchers at the leading edge of their field or to sustain a tight connection to the publicly funded research community, and firms differed greatly in the degree to which they invested in advanced biomedical research.

The ability to take advantage of the techniques of "guided search," in contrast, required a very substantial extension of the range of scientific skills employed by the firm—a scientific workforce that was tightly connected the larger scientific community and an organizational structure that supported a rich and rapid exchange of scientific knowledge across the firm...

For those firms that had already made the transition to guided drug discovery, the adoption of the tools of genetic engineering as an additional resource in the search for small molecule drugs was a fairly natural extension of existing competence base...

Although newly founded firms pioneered the use of genetics as a source of large molecular weight drugs, established firms led the way in the use of genetic technology as a tool for the discovery of traditional or small molecular weight drugs. The speed with which the new techniques were adopted varied enormously, however...

Firms such as Merck, Pfizer, and SmithKline-Beecham, for example, made the transition relatively straightforwardly. Those firms that had been more firmly oriented toward the techniques of random drug design, however, found the transition much more difficult.

—Iain Cockburn, University of British Columbia, Rebecca Henderson, Massachusetts Institute of Technology, Luigi Orsenigo, Università Commerciale Luigi Bocconi, and Gary Pisano, Harvard University

A similar biotechnology-based shift may be occurring in the chemicals industry as Dupont and Monsanto focus their product portfolios on agricultural and other life science products. Their manufacturing know-how differs and is not easily shared, supporting the competitive advantage of an individual firm.

### Other Innovation System Changes

These fundamental changes in information technologies and biotechnology remain linked to long-range research in electrical engineering, computer sciences, and molecular biology, but over the past decade or longer U.S. industries have evolved different ways of accessing research.[7] The large corporate research facilities of such companies as IBM, AT&T, Dupont, and Xerox were sharply reduced in size and, apparently, refocused on shorter-term product development. New corporate linkages to university research have been created, through direct funding by a single company of a particular university center, institute, or laboratory, through consortia such as the Semiconductor Research Corporation, or through faculty involvement in launching start-up companies.

Although the incidence and value to firms of outsourcing R&D are unclear, the increase in their frequency extends to the proliferation of joint research ventures, strategic alliances with foreign and other U.S. firms (many of them focused more on joint marketing than on R&D), and cooperative arrangements with federal laboratories through cooperative research and development agreements (CRADAs). The downsizing of some central corporate laboratories appears to have gone hand-in-hand with decentralizing the R&D function, perhaps linking it more tightly to business units and therefore to profit-making incentives.

**R&D and Innovation in the Steel Industry**

Although new innovations do affect competitiveness in the steel industry, there is no obvious trend between the industry's in-house R&D spending and its economic performance. R&D spending at the major integrated firms decreased drastically in the mid-1980s shortly before these firms began making their greatest increases in productivity, followed by increases in profitability. The minimill producers have little or no in-house R&D and yet have performed well during this same period. It could be argued that the minimills are living off the research of others. In

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[7]Appendix B reviews the national data relating to the generalizations in this section.

contrast, it is not clear whether major international firms such as Nippon Steel, Usinor, and POSCO have had good financial performance because of their relatively large investment in R&D, or if they were able to invest heavily in R&D because of good financial performance. Again, the question of how R&D spending is related to economic performance is not obvious in the global steel industry.

The improved economic performance of the U.S. steel industry may be due more to the effective use of R&D resources, capabilities, and the organization and less to the investment in R&D. When the integrated firms restructured their operations and reorganized their in-house R&D to cut costs and improve productivity, they lost a large part of their R&D capability and skills. However, the R&D organization became more efficient and focused more directly on production and issues relevant to customers. The in-house R&D organizations formed tighter relationships with production plants, suppliers, and customers. The acquisition of new technology innovations came more from other sources, including particular suppliers and foreign steel producers. The "not-invented-here" syndrome, which sometimes neglected advances made outside one's own company, that had prevailed prior to the 1980s disappeared almost completely...

In contrast, minimill producers have always effectively utilized innovations developed elsewhere. The U.S. minimills became international leaders in the commercialization of a series of processes that led to the development of continuous steel processing. This process improved the conversion time of raw materials to finished products from several months to ten hours or less. As such, the minimill sector has achieved astounding production efficiency and high profitability in the last two decades. The minimill industry's effective adoption and commercialization of innovations from other sources has been a large determinant of its competitiveness and economic success.

For the U.S. steel industry as a whole, R&D resources have been more effectively utilized, even as R&D resources have decreased dramatically.

—Richard Fruehan, Dany Cheij, and David Vislosky, Carnegie Mellon University

Increasingly, however, innovation in many industries is not traceable directly to any source, inside or outside a firm, with formal research as a major activity but is introduced from

- intermediary firms such as specialized engineering firms (SEFs) in chemical processing, consulting and accounting firms in information technologies, and logistic firms providing Global Positioning System (GPS)-based vehicle location systems to truckers and time-sensitive delivery systems to food retailers and apparel firms;

### Customer-Driven Technical Change in the Apparel Industry

New demands from other parts of the apparel production channel—upstream suppliers of fabric and particularly downstream retailers—and pressures from foreign competition are transforming the inflexible manufacturing-driven domestic production system. Unlike apparel, these other sectors are characterized by large firms and rising levels of concentration. For example, the four largest apparel retailers held 17.9 percent of the market in 1992, compared with 6.4 percent in 1972. The corresponding figures are 27.6 percent and 11.2 percent for women's specialty shops and 53.1 percent and 38.8 percent for department stores. Increased concentration, along with the availability of offshore suppliers, has shifted decision-making power within the production channel from clothing manufacturers to mass retailers.

Increased cost pressures following the wave of leveraged buyouts and mergers in retailing in the 1980s encouraged retailers to reduce the costs of inventories by adopting new information technologies, such as electronic point of sale (EPOS) data and computerized ordering and stock management programs. These cost-cutting practices are known as "lean retailing." The proliferation of clothing styles, colors, and sizes as well as the shortening of product life cycles in the 1980s further intensified the incentives for adopting lean retailing practices...

More products and more rapid style change tend to raise inventory and markdown costs and to increase the possibility of lost sales. They also raise uncertainty about consumer demand because there are fewer products with a market history and less time in a season to adapt to demand fluctuations...

In principle, just-in-time supply allows retailers to place smaller initial orders because replenishment supplies can be obtained throughout the selling season in response to actual sales. As a result, inventories, stockouts, and markdowns would be reduced. Just-in-time delivery is not consistent with the supply capabilities of the inflexible domestic progressive bundle system (PBS), however, and is beyond the reach of dis-

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tant offshore supply chains. Introducing a quick supply capability into domestic PBS supply channels has involved both a willingness among retailers to pay a cost premium for quick and accurate fulfillment of replenishment orders and to provide the information systems needed to link domestic clothing manufacturing to retail sales data.

The main instrument for building just-in-time supply chains has been the transfer of new information technologies from lean retailers to apparel manufacturers. Examples include electronic data interchange (EDI) of point-of-sale data between retailers and clothing manufactures and the use of EPOS computer programs to trigger quick-response shipments and initiate new production.

—Peter Doeringer and Audrey Watson, Boston University

- suppliers, customers, and marketing departments;
- trade associations such as the Food Marketing Institute that developed and promoted the Efficient Consumer Response system in retailing; and
- customers and/or suppliers demonstrating or developing new products or services of higher quality or with improved capability.

### Efficient Consumer Response in the Retail Food Industry

[Efficient consumer response (ECR)] is U.S. supermarkets' answer to their more competitive environment. The major goals are to produce and ship products in response to consumer demand, eliminate costs that do not add value, reduce inventories, spoilage, and paperwork, and simplify transactions between companies.

The ECR movement was launched after Wal-Mart and other discount mass merchandisers entered food retailing with supercenters. ECR is akin to "lean-inventory management" or "just-in-time delivery" in manufacturing. The purpose is to reduce costs by increasing the efficiency of distribution. The strategy calls for grocery retailers, wholesale distributors, and manufacture suppliers to be linked together electronically and to cooperate closely...

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The vision of ECR is that a timely, accurate, paperless flow of information starts at the checkout counter and facilitates a smooth, continuous flow of product that matches consumer purchases. Computers and software programs allow data to be transmitted directly to distributors and/or manufacturers in real time. This flow of information allows fast-moving items to be replenished automatically and makes it possible for manufacturers to adjust production lines in response to consumer demand. In contrast, in the past information circulated much more slowly and only in closed circles—between consumers and retailers, between retailers and wholesale distributors, and between wholesalers and food manufacturers and other suppliers.

To respond to the increased competition and need to improve efficiency, industry leaders formed the ECR working group in mid-1992. ECR was developed through the main trade associations to ensure that its benefits would be widely available...

The fundamental stimulus for the ECR initiative was the intensified competition from nonfood retailers, such as Wal-Mart. Moreover, it was known that Wal-Mart had plans to enter food retailing, which it has since done with its supercenters, combining discount general merchandise and food. Food retailing is a relatively low-tech, fragmented industry. The success of the ECR initiative depended on the backing and financial support of trade associations, especially FMI and the Grocery Manufacturers Association (GMA). In addition, the large manufacturers, such as Proctor and Gamble, were behind the ECR initiative and provided much of the necessary funding. Major food product manufacturers, such as Proctor and Gamble and Coca-Cola, have substantial research and development budgets, in contrast to the retailers. The manufacturers saw ECR as a way to increase their own efficiency and profitability by streamlining distribution in partnership with the retailers.

—Jay Coggins and Ben Senauer, University of Minnesota

The Board's case studies, especially of the service industries—trucking, food retailing, and banking—but also apparel, powder metal parts, and other manufacturers, underscore that efficient absorption and deployment of technology from external sources such as software, systems, consulting, and accounting firms, as well as suppliers, customers, and competitors, are themselves risky endeavors that, in addition to capital, require knowledge, skill experimentation, and analysis that for the most part are not classified as R&D.

## CONCERNS FOR THE FUTURE

The STEP Board believes that the goal of public policy should be (1) to sustain a high rate of growth of the economy over the long-term by removing sources of inefficiency and (2) to achieve a wider distribution of its benefits. The corporate strategies and apparently supportive public policies of the 1990s, although successful, almost certainly will need to be changed in the future to fit different circumstances. This race has no single clock and no finish line.

Moreover, several developments have undermined the stability associated with a world of vertically integrated firms with in-house R&D and proprietary technology. One is the emergence of specialized providers of R&D and technical services purveying expertise to all comers throughout the world and moving industrially relevant technologies more rapidly across national boundaries.

Several enduring characteristics of the American polity and economy probably bode well for the future. One is the sheer size of the domestic American market and the scale of its resources. A second is the remarkable flexibility of the political and economic systems, encouraging experimentation in the development and commercialization of new technology and providing relatively little protection for enterprises committed to established ways of doing business. A related factor is the culture's tolerance for failure. Finally, contrary to recent conventional wisdom about managers' and investors' myopia, markets over time, although they fluctuate, do a reasonably good job of favoring firms with high growth prospects.[8]

Despite the Board's general satisfaction with the progress of the past decade (and, taking a longer perspective, the postwar period) and our guarded optimism about America's economic future, the position of American industries in world markets requires further study and continual monitoring. In the meantime, our collective investigations raise four policy concerns that should be addressed: (1) the adequacy of measures and statistical data on research and innovation broadly defined; (2) the employment, income, and labor market effects of industrial resurgence and the adequacy of human capital to sustain it; (3) the implications for research, innovation, and technology diffusion of some aspects of the

[8]In their chapter, Landau and Arora (1999) present recent stock market data for a number of the leading companies and industry averages for most of the industries examined in the STEP project. Their comparison strongly suggests that investors perceive which companies are well managed and have reasonable prospects for growth. Two extreme examples are the extraordinarily high valuation of Microsoft, which has few tangible assets, and the low valuation of USX, a major steel producer with large physical assets, which is not seen as having a brilliant future or impressive technological capability. Companies in technologically progressive industries like computers, software, and pharmaceuticals are deemed to have better growth prospects than firms in industries that are not. That does not mean these underinvested industries are not important to the economy, but their failure to attract capital demonstrates their modest future prospects as global financial markets become more and more integrated. As the Euro becomes a strong rival to the dollar, more sound comparison of corporate growth potential can be made on an international basis.

continued extension of intellectual property rights protection; and (4) divergent trends in public and private investment in R&D infrastructure.

## Industrial Research and Innovation Data

Revealing as the Board believes the industry case studies are, the findings are anecdotal. Carefully selected statistical data, collected nationally on a recurring but not necessarily very frequent basis, also are needed to help discern and track changes in innovation processes as well as to help design and evaluate public policy measures affecting innovation. Unfortunately, the data gathered by the federal government and some private investigators shed little light on the structural changes in innovation processes described above. For example, industrial R&D spending data collected at the enterprise level rather than the business-unit level cannot be linked to particular products and services or locations and reflect shifts in competition, orientation, and organization only on the basis of broad industry categories of dubious value. Current science and technology indicators and data fall woefully short of illuminating a major part of the story of American industry in the 1990s—the origins of a variety of information technology products and services and their implementation in a cross-section of industries. This is because data on innovation-related activities and investments other than formal R&D and patenting are extremely limited. In particular,

- technology adoption is captured only in occasional surveys and only in the manufacturing sector;
- specialized technology providers (consulting, engineering, and systems firms, etc.) are not surveyed regularly;
- intersectoral flows of information are captured poorly, in part because data on the mobility and activities of technically trained people, the principal agents of technology transfer, are not adequately developed or exploited; and
- measures of the value of intellectual capital and innovation are lacking.

The STEP Board believes that in principle the following steps would greatly improve the information base for microeconomic policy design and evaluation, although questions of feasibility, burden and compliance, administration, and cost need to be examined:[9]

- R&D spending data should be collected at the business-unit level.

[9]The following were among the principal suggestions of scholars, analysts, industrialists, and policymakers participating in the STEP Board's February 1997 workshop on industrial research and innovation indicators for public policy (Cooper and Merrill, 1997).

- The government should conduct periodic innovation and technology adoption surveys in service as well as manufacturing industries.
- Emerging industries and intermediary organizations that play a key role in technology transfer and implementation should be included in appropriate surveys.
- Statistical agencies, scholars, universities, and professional associations should consider how human resources data (on training, career paths, and work patterns of technically trained people) can be improved and used to assess knowledge flows and innovation trends.
- Where possible, relevant currently collected datasets (e.g., R&D, patents, publications, employment) should be linked to each other and to geographic location by identifying information.
- Federal statistical agencies should explore whether public-private partnerships could produce information useful to both corporate managers and public policy makers at less cost and effort and with less burden on respondents.

## Labor Implications

The employment and income implications of technological and industrial change have been among the most contentious economic issues in the 1990s. One debate involves the extent of job displacement by downsizing, movement of operations offshore, or other factors and the effectiveness of public policies to assist workers' adjustment and retraining. A related issue is the apparent increase in wage differences between workers at the bottom and those at the top of the income distribution. This phenomenon is probably due in part to the fact that technological changes place a premium on skilled workers and put workers with minimal basic skills at further disadvantage. This income dispersion is moderated when other measures of welfare—total compensation and household consumption—are substituted for individual wages.

A third concern is that lack of an adequate, well-trained workforce may inhibit the capacity of the United States to remain prosperous and a locus of innovation. There is no doubt, in particular, about the great demand across most sectors of the U.S. economy and elsewhere for workers skilled in creating and developing information technologies. Innovation in and deployment of information technologies are straining the capacity of educational institutions and training programs to produce people with the necessary knowledge and skills to sustain this momentum. Immigration quotas have been raised, states and some firms have hastily expanded degree and training programs, and companies are paying higher premiums or accessing foreign skilled labor through foreign direct investment or telecommunications. What is not clear is whether, despite these measures, there will remain a critical shortfall between supply and demand and what if any steps should be taken to alleviate it.

## Intellectual Property Rights

In advanced industrial economies where, increasingly, intellectual assets are the principal source of value, productivity, and growth, strong intellectual property rights—conferred by patents, copyrights, and penalties for misappropriation of trade secrets—are an important inducement to invention and investment. For this reason, the extension and strengthening of IPRs in the United States and elsewhere in the past 25 years were appropriate and probably necessary. It may be that in some respects those processes should proceed further. On the other hand, there is growing friction over the assertion and exercise of some IPRs and claims that in some circumstances they may be discouraging research, its communication, and use. The question arises whether in some respects IPR strengthening and extension have proceeded too far.

Many enhancements of underlying IPR regimes reflect a greater professed appreciation of the incentive effects of protection on investment in R&D and use of intellectual property and appear to have had tangible results in a number of sectors, such as biotechnology and software. In recent years there has been an unprecedented surge in the overall number of U.S. patents applied for and granted to U.S. firms each year; and several major corporations, such as IBM, have made a great effort to exploit intellectual property through licensing. But these trends contrast with survey evidence suggesting that U.S. manufacturing firms in industries other than pharmaceuticals and chemicals rely more heavily on trade secrecy and lead time to recoup their R&D investments than they do on legal mechanisms such as patents and that, if anything, the effectiveness of patents as a means of appropriating R&D returns has *declined* since the early 1980s (Cohen et al., 1998).

In short, apart from pharmaceuticals and biotechnology, the effects of IPR changes on innovation and technical advance are highly uncertain—with respect to *either* the incentive provided to the innovator to capture the benefits of his invention, investment, and effort and therefore invest more resources and effort in innovation *or* the encouragement to the inventor to provide the information to others who might improve upon it. At the same time there are concerns about the manner in which IPRs are being asserted and exercised in some circumstances. These concerns can be categorized by their potential effects:

◆ *on the performance and communication of academic research*
- concern that an international agreement favored by the European Union and the U.S. Patent and Trademark Office to extend copyrights to scientific databases will inhibit research;
- concern that expressed gene sequence and other biological material patents will make it prohibitively complicated and expensive to conduct research using these tools or, alternatively, expose research investigators to infringement suits;
- concern that allowing federal grantees to obtain patents has altered their incentives to conduct basic versus applied research;

- concern that universities', researchers', and sponsoring companies' financial interests in exploiting academic results (by IPRs and otherwise) are inhibiting open, timely scientific communication; and
- concern that universities' and potential industry research sponsors' inability to resolve differences over IPRs will discourage corporate support of academic research.

◆ *on personnel mobility and informal technical communication between rival companies*

- concern that enforcement of new federal trade secrecy laws, providing civil and criminal penalties for misappropriation, will have a chilling effect on mobility and informal know-how trading among firms (von Hippel, 1987).

◆ *on industry investment in R&D and innovation, both radical and incremental, initial and subsequent innovation*

- concern about the uncertainty of the scope of IPRs;
- concern that slow and secret patent administration processes reduce R&D incentives;
- concern about high litigation uncertainties and costs, both financially and in terms of the time of scientists, engineers, and managers; and
- concern about licensing terms barring probing the intellectual content of software or genomic material and making modifications and improvements (so-called "decompilation")

◆ *on industry competition and structure*

- concern about the use of patent portfolios to block competitors' entry or discourage related research; and
- concern about the penalties for initial innovators (e.g., business software developers) when IPR protection shifts from trade secrecy to patents.

The STEP Board believes that broad reassessment of IPR policies is therefore timely. What have been the costs and benefits of the actions taken in the last several years? The unintended as well as intended consequences? What should be the direction of IPR policies in the next decade or two decades? Should there be different approaches to intellectual property protection depending on the subject matter?

## Long-Range Research

The improved competitive performance of many of the industries examined by the STEP Board has come about in the face of reductions in industry-funded longer-range research in some sectors. The industry case studies and limited national data suggest that this frequent observation applies to at least some of the industries reliant on the physical and information sciences, engineering, and mathematics—electronics, software, networking, and materials processing (steel, chemicals, and metal parts). Leading corporate performers of industrial research in the 1970s—AT&T, IBM, Kodak, DuPont, and Xerox—had by the mid-1990s all downsized, redirected, and restructured their activities, particularly those concentrated in central research facilities, out of economic necessity and, in all likelihood, with near-term benefits for corporate balance sheets. The fastest-growing firms in information technology—Intel, Sun Microsystems, and Microsoft—for the most part eschewed traditional large-scale research organizations. But this pattern has not extended to pharmaceutical companies, the new biotechnology enterprises that have become profitable, or the chemical firms that have shifted emphasis to life science products.

Since 1992, public investment in research as well as development has declined as a result of budget reduction pressures, but also unevenly. As a function of their dependence on agencies with changing missions and declining budgets overall—the Department of Defense (DOD), National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE)—certain fields of research have borne the brunt. They include most engineering and physical science fields, especially electrical and mechanical engineering, physics, and chemistry, although apparently not computer science and materials engineering. Together, the federal government's electrical engineering research support for all performers declined 36 percent between 1993 and 1997; university research support dropped 32 percent. There is little evidence that agencies' research portfolios (e.g. the National Science Foundation's) have been adjusted to compensate for the reductions in mission agencies' spending in these fields. At the same time, research in the biological and especially the medical sciences has benefited from steady growth in the budget of the National Institutes of Health, their principal source of support. Budget projections by agency through the year 2003 show a continuation of the same trends.[10]

NSF data on federal spending by field of research are available only through fiscal year 1997. In most cases, the reductions began to occur in fiscal year 1993. Five years is simply too short a period to be sure that these are long-term trends. Furthermore, agency research portfolios even in the same field differ markedly in character, so that a small reduction in one agency's budget might have a qualitatively more important impact on research in the field than a larger reduction in some other agency's spending. Determining how changes in spending by an

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[10]See Appendix A for a detailed analysis of the impact of federal budget changes through fiscal year 1997 on major research fields related to industrial activity. These data are presented in some detail here because, surprisingly, they have not been published elsewhere although the general trends have been observed by others including the Committee on Science, Engineering, and Public Policy (1998, 1999).

industry relate to changes in federal support of fields contributing to innovations in the industry would require a careful and detailed assessment.

Despite these caveats, the downward trend in public and private investment in certain fields of research is of concern because

- with a lag time, overall private R&D spending tends to follow the pattern of public spending, suggesting that a downward trend is difficult to reverse;
- the majority of federal investment in most research fields is, appropriately, a function of particular government missions and their political support; but the productivity of a field and its long-range prospects for contributing to successful applications may be neglected in the process of allocating resources to different programs; and
- although there is no reason that currently constituted research fields should continue to be supported at the same or increasing levels, there is apparently no mechanism for assessing support of fields of research related to industrial activity across agencies and for making adjustments in one agency's budget to compensate for another agency's spending reductions dictated by changes in the latter's mission.

The trends in several engineering and physical science disciplines are of sufficient concern to justify a selective effort to assess whether they are adverse and, if so, what steps should be taken to change them. Among the questions that need to be addressed in each assessment are the following:

- What kinds of research in what subfields are being negatively affected?
- Are investigators able to shift research sponsorship from federal agencies with declining budgets to agencies with increasing budgets?
- Is industry or another nonfederal source compensating for the decrease in public spending? [11]
- To what extent do changes in support levels reflect changes in research and technological opportunities?
- What are the sources of support for graduate education in the field and is there a direct relationship between research funds and graduate training support?

[11]For example, the nonprofit Microelectronics Advanced Research Corporation, a subsidiary of the industry-funded Semiconductor Research Corporation, is an industry-sponsored fund ($20 million in 1998) supporting long-range research at universities in technologies relevant to the semiconductor industry's technology roadmap. Its creation was motivated in part by concern about federal spending trends.

If there is judged to be a deficiency in investment, what is the solution? The obvious answer—increased spending, greater efficiency—beg the question "how?", especially when it may not be feasible or appropriate to increase a mission agency's budget to support a particular research field. Other approaches are:

- Encourage inter-agency coordination. Among other forms this might take, agencies could arrange to share research facilities, avoiding duplication of infrastructure spending and maximizing limited programmatic funds.
- Encourage government-industry coordination. The semiconductor industry's MARCO program is an example of a private sector effort to compensate for government retrenchment.
- Institute a balance wheel. This might entail identifying an agency as a focal point for monitoring one or more major fields of research, assessing the need to pick up slack resulting from other agencies' mission-driven decisions, and adjust its own research portfolio accordingly.[12]
- Undertake high-level priority setting. OMB and the Office of Science, Technology and Economic Policy might more directly take the health of key research fields into account in issuing budget preparation instructions, conducting budget cross-cut analyses, and negotiating agencies' budget requests.

## CONCLUSION

The STEP Board's inquiry about U.S. industrial performance was prompted by the contrast between the diagnosis in the 1980s of secular economic decline and permanent loss of competitiveness and the experience in the late 1990s of growth, profitability, and stock market acceleration. In part the earlier pessimism was a function of the narrow focus on manufacturing industries and overestimation of their foreign competition. But it is also true that underlying U.S. strengths in innovation were masked by adverse macroeconomic conditions, especially high interest rates and the high valuation of the dollar. The resurgence is therefore partly macroeconomic—the combination of steady conservative fiscal policy producing low domestic inflation, interest, and exchange rates—and partly microeconomic—the combination of diverse regulatory, trade, and research policies and the responses of U.S. firms to domestic and foreign competition, new market opportunities, and technological change.

Hindsight yields cautionary lessons, however. Satisfaction with the resurgence and confidence in its sustainability run the risks of discounting the vulnerability of the macroeconomic environment and ignoring microeconomic trends

[12]This is a recommendation of the Committee on Science, Engineering, and Public Policy in its recent report, *Evaluating Federal Research Programs* (1999).

that may seriously undermine performance in the future. In the Board's judgment, four issues that merit attention are 1) the adequacy of measures and statistical data on research and innovation broadly defined; 2) the adequacy of human capital to sustain the resurgence; 3) the implications for research, innovation, and technology diffusion of the continued expansion of intellectual property rights protection; and 4) divergent trends in public and private investment in R&D and infrastructure. Short-term strong performance does not necessarily signify a long-term trend unless supporting institutions and policies are both strengthened and adapted.

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# Appendix A

# Recent Trends in Federal Spending on Scientific and Engineering Research: Impacts on Research Fields and Graduate Training

Michael McGeary and Stephen A. Merrill

## AGGREGATE AND AGENCY TRENDS

The federal government has funded a large share of national research and development (R&D) since World War II. It was the largest funder until 1980 when it was surpassed by private industry. In 1998 (the most recent year for which expenditure data are available) it still provided 40.9 percent of all funding for research, basic and applied, carried out in university laboratories and medical centers, industrial and federal laboratories, and other research facilities in the United States.[1]

Real growth in the federal R&D budget—that is, growth in excess of inflation—began to level off in the late 1980s, and after 1992 it fell as part of the effort to reduce the federal budget deficit.[2] According to data collected by the National Science Foundation (NSF) on actual research obligations, federal spending on the research part of R&D peaked in 1993 and by 1997 was 2.2 percent less in real terms.[3]

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[1] That is 56.7 percent of basic research and 30.0 percent of applied research. Industry spending on research did not exceed the federal government's support until 1995. Calculated from National Science Foundation (1998a, Tables B-2B (basic research) and B-3B (applied research)). See Box A-1 for definitions of basic research, applied research, and development.

[2] Budget authority for R&D fell 8.8 percent in real terms between 1992, its historical high point, and 1997 (AAAS, 1998). Budget authority is legal authority to incur financial obligations that will result in outlays.

[3] Obligations are commitments to spend money, although actual payment may be made later, for example, under multiyear contracts.

As Table A-1 indicates, the trend in research funding has not been uniform across agencies.

Much of the decline has been in defense research, because of the end of the Cold War and changed national security requirements. The Department of Defense's (DOD) support of research was down substantially in both relative and absolute terms between 1993 and 1997. Other agencies that spent less in real terms in 1997 than in 1993 included the Department of Energy (DOE), U.S. Department of Agriculture (USDA), and the Department of the Interior (DOI). But what would have been a $2 billion decline was largely offset by increases in other agencies, especially the National Institutes of Health (NIH), NSF, and the National Aeronautics and Space Administration (NASA), so that the net decrease was just $173.6 million in 1998 dollars.

Federal support of basic research did not decrease between 1993 and 1997. Although the aggregate level of basic research funding dipped for several years after 1993, it was up again slightly—by 1.5 percent—in 1997 over 1993 in real terms. This occurred in part because of real growth in research spending by agencies that favor basic research, NIH and NSF, which offset decreases at DOD, DOE, and other agencies with shrinking research budgets. In 1993, 66 percent of NIH's research budget and 93 percent of NSF's were classified as basic research;

**TABLE A-1** Trends in Federal Research Funding Obligations, FY 1993-1997 (millions of 1998 dollars)

| | | | Change, 1993-1997 | |
|---|---|---|---|---|
| | FY 1993 | FY 1997 | Amount | Percent |
| DOD | 5,353.7 | 3,882.0 | -1,471.6 | -27.5 |
| NASA | 3,971.7 | 4,264.2 | 292.5 | 7.4 |
| DOE | 3,850.3 | 3,635.3 | -214.9 | -5.6 |
| DHHS[a] | 10,288.3 | 11,440.9 | 1,152.5 | 11.2 |
| *NIH* | *9,668.2* | *10,719.0* | *1,050.9* | *10.9* |
| NSF | 2,106.2 | 2,291.1 | 184.9 | 8.8 |
| USDA | 1,400.9 | 1,314.6 | -86.3 | -6.2 |
| DOI | 649.2 | 563.1 | -86.1 | -13.3 |
| EPA[b] | 404.6 | 416.9 | 12.3 | 3.0 |
| DOC[c] | 651.5 | 823.4 | 171.9 | 26.4 |
| Others | 1,419.4 | 1,290.7 | -128.7 | -9.1 |
| Total research | 30,095.7 | 29,922.1 | -173.6 | -0.6 |

[a]Department of Health and Human Services.
[b]Environmental Protection Agency.
[c]Department of Commerce.
Note: Constant-dollar conversions were made using the Gross Domestic Product (GDP) deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**BOX A-1**
**Definitions of R&D**

Common definitions of basic research, applied research, and development are used by the Office of Management and Budget (OMB), the American Association for the Advancement of Science (AAAS), and NSF, the sources of data in this paper. NSF uses the same definitions in its survey of industry. They are also generally consistent with international definitions. The objective of *basic research* is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. The objective of *applied research* is to gain knowledge or understanding to meet a specific recognized need. *Development* is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods. [4]

the percentages in 1997 were largely unchanged. As a group, agencies other than NIH and NSF spent 7.7 percent less on basic research in 1997 than in 1993 in real terms.

In short, although federally funded research does not appear to have suffered greatly from the decline in R&D that took place after 1992, the overall average downturn and the modest recovery since 1996 obscure the fact that research spending by some agencies has declined much more than others. Moreover, the agencies with declining or stagnant research budgets also turn out to be the primary funders of certain fields of research (Table A-2). In 1993, for example, DOD provided the majority of federal support of research in electrical engineering (82 percent), mechanical engineering (75 percent), materials engineering (73 percent), and computer science (57 percent). DOE provided the majority of funding for physics research (62 percent) and was the single largest supporter of chemical engineering (42 percent) and chemistry (29 percent). NASA provided the majority of funding for four other fields: aeronautical engineering (81 percent), astronautical engineering (79 percent), astronomy (76 percent), and atmospheric sciences (52 percent).

## ISSUES

It was inevitable that R&D expenditures would be affected by the bipartisan consensus to reduce the budget deficit, and it is not very surprising that agency

[4] For full definitions, see NSB (1998, pp. 4–9).

**TABLE A-2** Top Federal Funders of Research by Field, FY 1993 (percent of total federal funding)

| | DOD | DOE | NASA | NIH | NSF | USDA | Other |
|---|---|---|---|---|---|---|---|
| Engineering | | | | | | | |
| Aeronautical | 18.3 | | **81.4** | | 0.3 | | |
| Astronautical | 21.3 | | **78.7** | | | | |
| Chemical | 28.4 | 42.2 | | | 15.8 | | 13.6 |
| Civil | 39.4 | 12.5 | | | | | 48.1 |
| Electrical | **82.1** | 4.9 | | | 6.8 | | 6.2 |
| Mechanical | **75.4** | 8.6 | | | 7.4 | | 8.6 |
| Metallurgy & materials | **73.3** | 9.6 | 6.0 | | | | 11.1 |
| Physical Sciences | | | | | | | |
| Astronomy | 2.2 | | **75.8** | | 16.0 | | 6.0 |
| Chemistry | 16.6 | 29.2 | | 16.9 | | | 37.3 |
| Physics | 18.1 | **61.9** | 10.6 | | | | 9.4 |
| Life Sciences | | | | | | | |
| Biological | | 3.8 | | **82.4** | 4.5 | | 9.3 |
| Environmental biology | | | | | 13.8 | 34.2 | **52.0** |
| Agricultural | | | | | | **82.0** | 18.0 |
| Medical | 5.1 | | 2.4 | **83.5** | | | 9.0 |
| Mathematical & computer sciences | | | | | | | |
| Mathematics | 27.8 | 23.7 | | | 28.5 | | 20.0 |
| Computer sciences | **57.3** | 12.5 | | | 15.4 | | 14.8 |
| Environmental Sciences | | | | | | | |
| Atmospheric | | | **52.3** | | 13.1 | | 34.6 |
| Geological | | | 21.6 | | 17.2 | | **61.2** |
| Oceanography | 18.5 | | 23.0 | | | | **58.5** |

Note: Percentages greater than 50 percent are in bold to highlight dominant funders.
Source: National Science Foundation (1998b).

R&D budgets would change with circumstances as historic as the dissolution of the Soviet Union. Agency missions change and with them the resources for functions that support the missions. Nevertheless, the trends in agency budgets have raised three concerns:

1. First, that the nation's capacity and productivity in fundamental longer-range research may be harmed by shorter-term trends, including declining support of research by certain federal mission agencies, especially if there is a trend in private industry to focus on projects with nearer-term payoffs.[5]

2. Second, that because of the dependence of certain research fields such as physics, engineering, computer science, and mathematics on agencies with declining budgets, their health could be endangered for reasons unrelated to

[5] See Appendix B for an assessment of the evidence on this point.

their productivity or opportunities for significant research advances but rather as an unintended consequence of changing agency mission requirements.

3. Third, that because research grants to university investigators are the principal source of federal funds for the production of highly trained people in those science and engineering disciplines, graduate training could also be curtailed inadvertently.

## FUNDING TRENDS BY RESEARCH FIELD

We have seen that the research budgets of some of the largest R&D agencies have fallen or have not grown significantly. Some of those agencies, notably DOD, DOE, and NASA, provide the majority of funding in most fields of engineering, physical sciences, mathematics, and computer sciences. Some of the fields, for example, physics, computer science, electrical engineering, and materials engineering, are important to innovation in information technologies and to national economic performance generally. This situation raises a set of important questions:

- How and to what extent have changes in federal agencies' research budgets affected the funding of fields dependent on them?
- Are the changes invariably in the same direction?
- Is there evidence of an effort to protect certain performers (e.g. universities) even in fields experiencing declining federal support overall?
- Are there cases in which one agency has compensated for reduced support by another agency?
- Is there evidence that a mechanism exists for making such adjustments to maintain a balanced research portfolio?
- Do changes in graduate student support parallel changes in levels of research funding?

This paper relies on a series of annual surveys conducted by NSF's Division of Science Resources Studies (SRS) to attempt a preliminary test of these questions. The SRS survey of federal funds for R&D includes retrospective reports of agencies' actual obligations by fiscal year. The information is collected in a number of relevant categories that can be cross-tabulated in useful ways for an analysis of trends in federal research funding. For example, federal obligations for research are classified as basic research or applied research in 19 natural science and engineering fields.[6] Research performed by universities and colleges

[6] The NSF survey also includes obligations for research in the social and behavioral sciences. In addition, the agencies report funding of research "not elsewhere classified" for each broad field, such as life sciences and engineering, and for research that cannot be attributed to any broad field (see Table A-3 and footnote 9).

but not federally funded research performed in industry or government laboratories can be separately tabulated by field and/or whether it is basic or applied research.[7] The ability to consider funding by agency and field of research makes it possible to assess whether the trend in an agency's level of research funding is correlated with trends in the funding of fields of which that agency has been the primary funder.

SRS also conducts an annual survey of university departments that includes reports of the principal source of support for each graduate student in science and engineering, including federally funded mechanisms such as fellowships, traineeships, and research assistantships. This information is reported for most of the research fields included in the federal funds report. Thus, trends in federal support of graduate students in those fields can be related to trends in the overall number of graduate students.

Both surveys—of federal R&D obligations and graduate student support—lag events because they are retrospective. For example, NSF recently released data from the survey of actual obligations during FY 1997 approximately 15 months after the end of the fiscal year. This permits analysis of trends in funding by field and agency during the period of budget cuts—fiscal years 1993 to 1997. A data series of just five years is too short a period to be very sure lasting trends exhibited by individual fields will be, but it is sufficient to derive tentative conclusions with regard to the broad questions posed above.[8]

Another obvious caveat is that quantitative changes in funding reveal little about the character of the research being cut or increased and therefore little about the qualitative effects of the changes in funding. It may be that a small change in one agency's support would have a far more profound effect on research and training in a field than a more substantial change in funding of research with a different character. The evolving orientation of some research fields is also difficult or impossible to discern from the data, although there is some effort to capture inter- and multidisciplinary research.[9]

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[7] Although the nomenclature corresponds to academic disciplines and departments, in NSF's Federal Funds Survey it is applied to R&D performed in industry and government laboratories and by other nonprofit institutions. Obligations for "development" are not reported by field.

[8] The surveys ask agencies to estimate future research allocations for seven broad fields for research—e.g., physical sciences, life sciences, math/computer sciences, engineering, etc.—but these estimates are too general to be very useful to this analysis of impacts on specific fields.

[9] In the Federal Funds Survey, multidisciplinary or interdisciplinary projects that do not fall within one of the broad fields of science (e.g., engineering, physical sciences, life sciences) are to be reported as "Other science, n.e.c.," where "n.e.c." means "not elsewhere classified." Multidisciplinary projects that fall within a broad field and single-discipline projects that cannot be classified within one of the listed subfield categories are to be reported as "Engineering, n.e.c." or "Mathematics & computer sciences, n.e.c.," etc. As shown in Table A-3, the n.e.c. categories are quite large in engineering and environmental science and much smaller in other major fields. They have been growing in most major fields but not very rapidly. All "n.e.c." research combined was 12.8 percent of total federal research in 1993 and 14.1 percent in 1997.

There is also a complication with the data reported by NSF on the survey. Beginning with FY 1996, NSF changed its procedures for classifying research obligations by field. The change most affected engineering. The amount classified as "engineering, n.e.c." went from about 20 percent of the total in 1995 to about 40 percent after that year. Mechanical engineering went from 13 percent to 2 percent of engineering research funding. The physical sciences were also affected. The amount classified as "physical sciences, n.e.c" increased from about 9 percent in 1995 to 26 percent in 1997. It appears that this involved moving research previously classified astronomy, chemistry, and physics into the n.e.c. category. Environmental sciences were also affected, except that atmospheric, geology, and "environmental sciences, n.e.c." research were each apparently reclassified as oceanography. As a result, as we analyze affected fields such as mechanical engineering, we must take into account the extent to which NSF's new classification scheme might affect the results. The change will also affect our ability to ascertain how much NSF might have compensated for cutbacks in the support of fields by other agencies.

The research obligation trends by field are summarized in Table A-3. The findings reported in the following section are for a number of fields related to industrial activity.[10]

## Fields with Declining Support

Fields whose federal support declined from 1993 to 1997 included electrical engineering, mechanical engineering, physics, chemical engineering, chemistry, and geology. Although several of these fields had DOD or DOE as a dominant[11] funder in 1993, others (chemistry, chemical engineering, and geology) had quite diversified support.

### *Electrical Engineering*

In 1993 DOD provided 82 percent of the federal funding for electrical engineering. DOD support dropped 40.3 percent between 1993 and 1997 in real terms, which accounted for most of the net drop of 35.7 percent in federal support of the field (see Figure A-1 and Table A-4). In this case there were simultaneous decreases at DOE and NSF. The only increase of significance—90.4 percent—was at the Department of Commerce (DOC) presumably because of the growth of the Advanced Technology Program at the National Institute for Standards and

[10] Data for fields not included here (i.e., astronomy, astronautical engineering, agricultural sciences, environmental biology, psychology, and social sciences) are available at www4.nas.edu/pd/step/23ba.nsf, as are tables in current dollars for all of the fields in the survey.

[11] "Dominant" funder is defined here as providing 50 percent or more of the federal support for a research field.

**TABLE A-3** Constant Dollar Changes in Federal Obligations for Research, Selected Fields, All Versus University Performers, FY 1993–1997 (millions of constant 1998 dollars)

| | All Performers | | | Universities | | |
|---|---|---|---|---|---|---|
| | 1993 | 1997 | % Change | 1993 | 1997 | % Change |
| All fields | 30,095.7 | 29,922.1 | -0.6 | 10,681.9 | 10,984.3 | 2.8 |
| Engineering, total | 6,154.9 | 5,798.1 | -5.8 | 993.8 | 1,006.7 | 1.3 |
| Aeronautical | 1,335.2 | 1,378.3 | 3.2 | 58.3 | 50.2 | -13.8 |
| Astronautical | 552.9 | 607.6 | 9.9 | 22.8 | 17.9 | -21.5 |
| Chemical | 274.8 | 239.4 | -12.9 | 73.2 | 63.9 | -12.7 |
| Civil | 282.0 | 280.8 | -0.4 | 42.2 | 46.0 | 8.9 |
| Electrical | 986.6 | 634.0 | -35.7 | 219.0 | 149.1 | -31.9 |
| Mechanical | 522.6 | 259.4 | -50.4 | 131.3 | 77.6 | -40.9 |
| Metallurgy/materials | 778.6 | 877.0 | 12.6 | 224.5 | 266.2 | 18.5 |
| Engineering, n.e.c. | 1,422.4 | 1,521.5 | 7.0 | 222.4 | 335.8 | 51.0 |
| Physical Sciences, total | 4,954.7 | 4,227.3 | -14.7 | 1,312.4 | 1,186.0 | -9.6 |
| Astronomy | 768.1 | 789.4 | 2.8 | 134.4 | 171.2 | 27.4 |
| Chemistry | 943.7 | 861.5 | -8.7 | 389.4 | 347.4 | -10.8 |
| Physics | 2,952.9 | 2,106.8 | -28.7 | 680.5 | 532.0 | -21.8 |
| Physical sciences, n.e.c. | 290.1 | 469.6 | 61.9 | 108.1 | 135.4 | 25.3 |
| Life Sciences, total | 12,056.1 | 12,901.3 | 7.0 | 6,156.1 | 6,690.5 | 8.7 |
| Biological sciences | 5,360.8 | 5,421.0 | 1.1 | 3,072.7 | 3,566.9 | 16.1 |
| Environmental biology | 622.8 | 593.6 | -4.7 | 179.6 | 149.4 | -16.8 |
| Agricultural sciences | 797.9 | 653.5 | -18.1 | 167.0 | 176.4 | 5.6 |
| Medical sciences | 4,929.4 | 5,637.6 | 14.4 | 2,614.9 | 2,585.4 | -1.1 |
| Life sciences, n.e.c. | 345.0 | 595.7 | 72.6 | 121.9 | 212.5 | 74.3 |
| Mathematics & Computer Sciences, total | 1,371.5 | 1,703.5 | 24.2 | 548.5 | 582.4 | 6.2 |
| Mathematics | 325.5 | 307.3 | -5.6 | 152.1 | 130.7 | -14.0 |
| Computer sciences | 924.6 | 1,288.7 | 39.4 | 378.1 | 427.2 | 13.0 |
| Mathematics & computer sciences, n.e.c. | 121.4 | 107.5 | -11.5 | 18.4 | 24.6 | 33.8 |
| Environmental Sciences, total | 2,919.4 | 3,103.4 | 6.3 | 660.8 | 684.8 | 3.6 |
| Atmospheric | 1,101.4 | 1,186.4 | 7.7 | 178.6 | 209.7 | 17.4 |
| Geological | 893.0 | 704.9 | -21.1 | 211.0 | 126.6 | -40.0 |
| Oceanography | 523.1 | 609.0 | 16.4 | 164.2 | 219.5 | 33.7 |
| Environmental sciences, n.e.c. | 402.0 | 603.0 | 50.0 | 107.0 | 129.1 | 20.7 |

**TABLE A-3** Continued

| | All Performers 1993 | All Performers 1997 | % Change | Universities 1993 | Universities 1997 | % Change |
|---|---|---|---|---|---|---|
| Social Sciences, total | 755.3 | 709.5 | -6.1 | 241.7 | 201.1 | -16.8 |
| Psychology, total | 616.3 | 555.7 | -9.8 | 321.8 | 288.8 | -10.3 |
| Other sciences, n.e.c. | 1,267.5 | 923.3 | -27.2 | 446.8 | 344.0 | -23.0 |

Note: All performers include federal intramural laboratories, industrial laboratories, universities and colleges, other nonprofit research institutions, national laboratories, and other federally funded research and development centers, state and local governments, foreign performers, and private individuals.
Source: National Science Foundation (1998b).

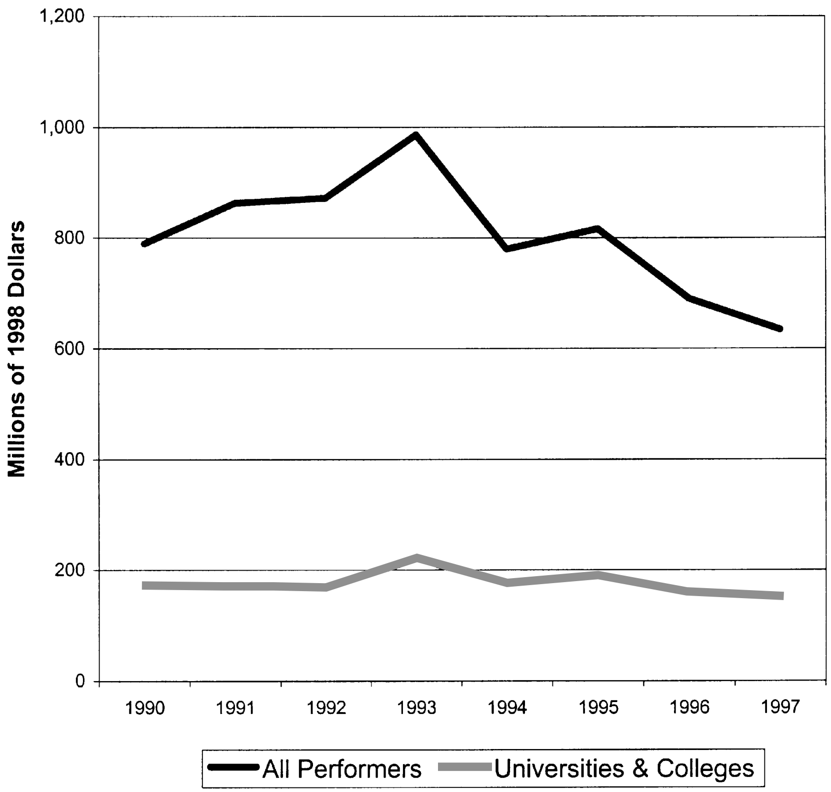



**FIGURE A-1** Constant dollar trends in federal funding of electrical engineering research, FY 1990-1997.
Source: Tables A-4 and A-5.

Technology (NIST), but DOC's program is so small that nearly doubling it only reduced the drop that would have occurred in overall federal support by about 6.4 percentage points.

The results were similar for electrical engineering research conducted at universities and colleges (see Table A-5). The falloff in DOD support accounted for most of the net drop of 31.9 percent in federal funding of university research in electrical engineering in 1997. NSF also reduced its support by 25.4 percent.

**TABLE A-4** Federal Obligations for Electrical Engineering Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.5 | 0.7 | 0.8 | 0.8 | 0.5 | 0.5 | 0.3 | 0.6 | -0.2 | -20.5 |
| Commerce | 15.3 | 18.1 | 23.9 | 26.9 | 31.3 | 60.0 | 51.2 | 51.1 | 24.3 | 90.4 |
| DOD | 659.9 | 691.0 | 706.5 | 809.6 | 596.8 | 609.3 | 533.0 | 483.3 | -326.3 | -40.3 |
| DOE | 26.0 | 50.7 | 44.5 | 48.2 | 46.2 | 54.7 | 25.8 | 24.7 | -23.5 | -48.7 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 0.9 | 1.1 | 0.9 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | -0.1 | -52.8 |
| EPA | 0.6 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 14.2 | 19.7 | 17.0 | 23.4 | 24.8 | 25.5 | 25.4 | 25.5 | 2.0 | 8.7 |
| NSF | 61.0 | 68.4 | 61.2 | 67.1 | 72.7 | 60.8 | 44.2 | 43.0 | -24.1 | -35.9 |
| All others | 11.1 | 12.2 | 16.2 | 10.3 | 6.8 | 5.1 | 9.1 | 5.6 | -4.7 | -45.3 |
| TOTAL | 789.4 | 863.1 | 871.9 | 986.5 | 779.2 | 816.0 | 689.3 | 634.0 | -352.5 | -35.7 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-5** Federal Obligations for University Research in Electrical Engineering, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 106.4 | 92.7 | 104.1 | 150.6 | 105.1 | 130.4 | 103.9 | 96.3 | -54.3 | -36.0 |
| DOE | 2.4 | 2.8 | 2.2 | 2.7 | 1.5 | 3.2 | 2.3 | 2.1 | -0.6 | -21.9 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 10.7 | 10.9 | 8.0 | 9.1 | 9.5 | 8.0 | 9.6 | 8.4 | -0.7 | -7.5 |
| NSF | 51.0 | 62.0 | 56.4 | 56.6 | 60.3 | 46.6 | 41.9 | 42.3 | -14.4 | -25.4 |
| TOTAL | 170.4 | 168.8 | 170.6 | 219.0 | 176.4 | 188.3 | 157.7 | 149.1 | -69.9 | -31.9 |

Notes: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Mechanical Engineering*

Federal support of mechanical engineering research followed a pattern very similar to electrical engineering. DOD, which provided 75 percent of all federal funding for mechanical engineering research in 1993, reduced its real level of funding of the field by 52.4 percent in 1997 (Figure A-2 and Table A-6). The next two largest federal funders, DOE and NSF, also reported that they had reduced their levels of support. As a result, net federal support of mechanical engineering research was 50.4 percent less in 1997 than in 1993 in real terms, as reported in the NSF survey. Mechanical engineering, however, is one of the fields affected by NSF's change in classification procedures. If we assume that

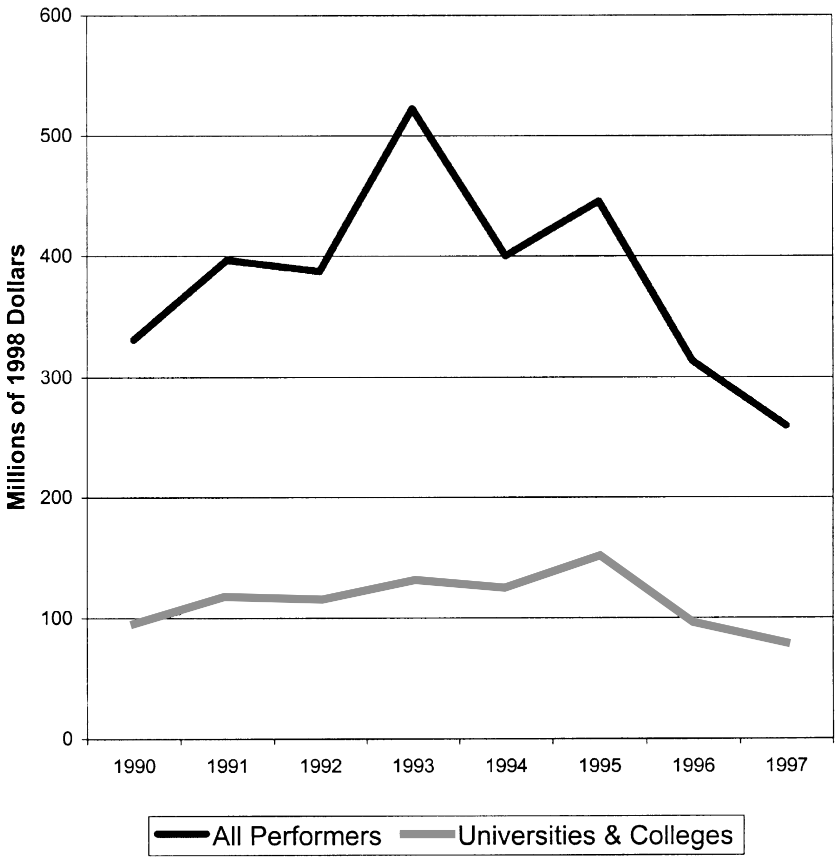



**FIGURE A-2** Constant-dollar trends in federal funding of mechanical engineering research, FY 1990–1997.
Source: Tables A-6 and A-7.

the amount of research NSF classified as mechanical engineering in 1993 has stayed at the same funding level in real terms, then overall federal support fell by 44.3 percent in 1997.

The same agencies, DOD, DOE, and NSF, reduced their support of university research (see Table A-7). Net federal support for mechanical engineering research was 40.9 percent less in 1997 than in 1993. If NSF funding is held constant in real terms, the drop is 20.9 percent.

**TABLE A-6** Federal Obligations for Mechanical Engineering Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 5.3 | 5.2 | 4.1 | 3.9 | 3.7 | 3.6 | 3.4 | 3.1 | -0.8 | -20.2 |
| Commerce | 1.8 | 3.4 | 3.4 | 5.4 | 5.6 | 7.1 | 5.5 | 4.4 | -1.0 | -19.0 |
| DOD | 225.3 | 234.5 | 246.5 | 394.0 | 276.5 | 291.9 | 240.6 | 187.4 | -206.6 | -52.4 |
| DOE | 21.8 | 58.0 | 49.9 | 44.8 | 40.5 | 40.1 | 18.3 | 17.0 | -27.8 | -62.0 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 0.9 | 1.5 | 0.9 | 0.2 | 0.9 | 0.9 | 0.2 | 0.2 | -0.1 | -25.8 |
| EPA | 4.9 | 2.7 | 4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 19.5 | 22.5 | 15.7 | 17.5 | 18.5 | 19.0 | 18.6 | 18.6 | 1.1 | 6.2 |
| NSF | 36.5 | 47.5 | 38.9 | 38.9 | 39.7 | 60.6 | 7.7 | 7.5 | -31.4 | -80.7 |
| All others | 15.0 | 21.3 | 23.7 | 17.8 | 14.6 | 22.2 | 19.1 | 21.2 | 3.4 | 19.2 |
| TOTAL | 330.9 | 396.7 | 387.4 | 522.5 | 400.0 | 445.5 | 313.4 | 259.4 | -263.1 | -50.4 |

Note: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-7** Federal Obligations for University Research in Mechanical Engineering, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 40.1 | 46.9 | 54.4 | 73.8 | 66.9 | 76.8 | 64.3 | 50.6 | -23.2 | -31.4 |
| DOE | 11.6 | 12.8 | 11.3 | 11.5 | 9.3 | 9.0 | 11.7 | 10.2 | -1.3 | -11.5 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 11.2 | 13.5 | 11.8 | 12.8 | 12.5 | 10.7 | 12.2 | 9.8 | -3.0 | -23.7 |
| NSF | 32.7 | 43.0 | 36.3 | 33.2 | 35.7 | 54.3 | 7.5 | 7.1 | -26.2 | -78.7 |
| TOTAL | 95.6 | 116.4 | 113.8 | 131.3 | 124.4 | 150.9 | 95.7 | 77.6 | -53.7 | -40.9 |

Notes: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Physics*

DOE is the largest federal funder of physics research, accounting for 62 percent in 1993, followed by DOD, which supported 18 percent. Physics research at DOE and DOD sustained real cuts of 28.6 and 63.2 percent, respectively (see Figure A-3 and Table A-8). NSF also reduced its support of physics research by 28.0 percent. Although several other agencies (e.g., Commerce, NASA) maintained or increased their funding of physics research, federal funding fell 28.7 percent between 1993 and 1997. University physics research did a little better, losing 12.5 percent of its federal support in real terms in the same period (see

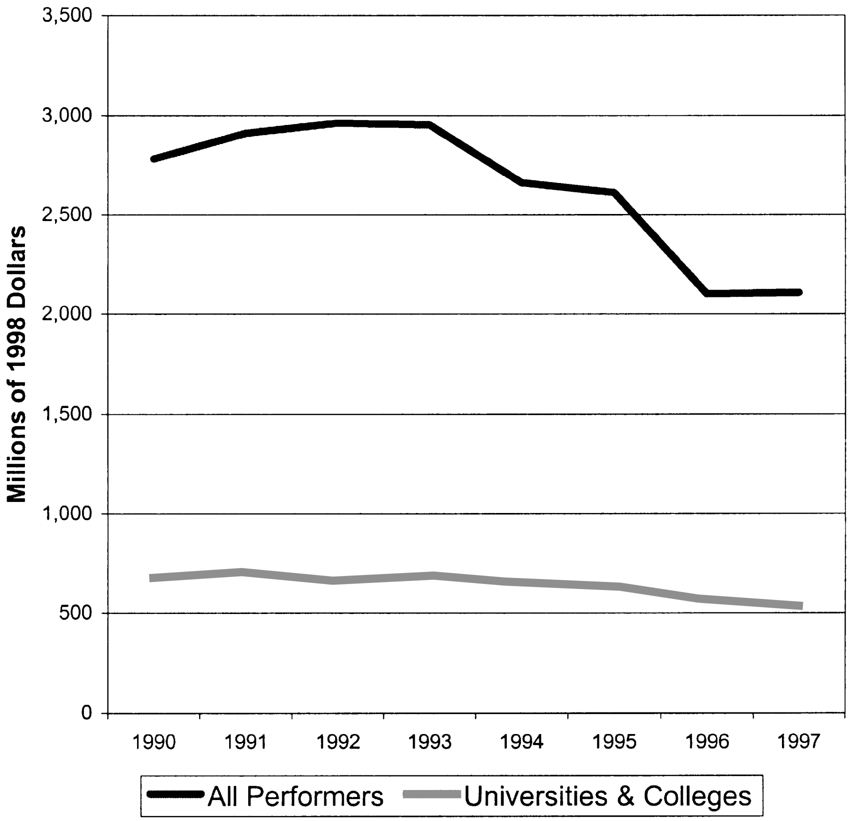



**FIGURE A-3** Constant dollar trends in federal funding of physics research, FY 1990–1997.
Source: Tables A-8 and A-9.

Table A-9). Holding NSF constant, because some research classified as physics in 1993 was reclassified as "physical sciences, n.e.c." in 1997, the drop in federal funding would be 26.9 percent in total support and 6.3 percent in university support.

**TABLE A-8** Federal Obligations for Physics Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | | | | | | | | | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Amount | Percent |
| USDA | 5.1 | 5.2 | 4.5 | 4.3 | 4.9 | 4.6 | 4.8 | 4.4 | 0.1 | 2.6 |
| Commerce | 48.9 | 48.9 | 50.9 | 57.1 | 63.7 | 61.4 | 63.1 | 64.6 | 7.5 | 13.2 |
| DOD | 382.4 | 434.7 | 468.6 | 534.4 | 421.6 | 394.3 | 217.5 | 196.5 | -337.9 | -63.2 |
| DOE | 1,697.2 | 1,770.2 | 1,859.2 | 1,829.2 | 1,623.2 | 1,597.8 | 1,251.5 | 1,306.5 | -522.7 | -28.6 |
| DHHS | 20.8 | 26.5 | 20.3 | 22.8 | 20.7 | 19.4 | 17.9 | 19.1 | -3.8 | -16.5 |
| *NIH* | *4.6* | *5.2* | *5.9* | *7.6* | *6.8* | *11.4* | *10.5* | *19.1* | *11.5* | *151.1* |
| Interior | 5.5 | 6.5 | 4.5 | 4.6 | 6.8 | 6.8 | 7.4 | 7.2 | 2.7 | 58.2 |
| EPA | 4.9 | 3.0 | 5.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 380.3 | 373.9 | 330.8 | 314.5 | 332.3 | 341.3 | 324.6 | 329.3 | 14.8 | 4.7 |
| NSF | 234.4 | 238.5 | 215.0 | 181.6 | 183.3 | 183.4 | 178.4 | 130.8 | -50.8 | -28.0 |
| All others | 1.6 | 2.5 | 2.1 | 4.4 | 5.8 | 3.1 | 34.8 | 48.4 | 44.0 | 995.1 |
| TOTAL | 2,781.1 | 2,909.9 | 2,961.7 | 2,952.8 | 2,662.3 | 2,611.9 | 2,099.9 | 2,106.8 | -846.1 | -28.7 |

Note: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-9** Federal Obligations for University Research in Physics, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | | | | | | | | | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Amount | Percent |
| USDA | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | NA |
| DOD | 69.4 | 62.8 | 72.4 | 86.7 | 68.3 | 75.3 | 37.8 | 56.0 | -21.5 | -27.8 |
| DOE | 281.4 | 310.0 | 282.6 | 289.7 | 283.5 | 288.9 | 274.9 | 282.1 | 23.3 | 9.0 |
| DHHS | 4.6 | 5.2 | 5.9 | 7.6 | 6.8 | 11.4 | 10.5 | 3.3 | -3.5 | -51.0 |
| *NIH* | *4.6* | *5.2* | *5.9* | *7.6* | *6.8* | *11.4* | *10.5* | *3.3* | *-3.5* | *-51.0* |
| NASA | 89.1 | 90.6 | 96.9 | 115.7 | 108.5 | 70.7 | 59.5 | 62.2 | -41.2 | -39.8 |
| NSF | 229.3 | 229.4 | 201.0 | 180.7 | 181.9 | 181.9 | 176.4 | 128.2 | -33.3 | -20.6 |
| TOTAL | 673.8 | 698.7 | 658.9 | 680.5 | 649.2 | 628.3 | 559.1 | 532.0 | -76.0 | -12.5 |

Notes: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Mathematics*

DOD support for mathematics research by all performers suffered a steep decline (nearly 50 percent) between 1993 and 1997, but this was partially offset by increased support by DOE and DHHS (not NIH) and to a lesser extent NASA, so that the overall drop was only 5.6 percent. NSF support remained flat (see Figure A-4 and Table A-10).

Support of mathematics research at universities fell by 14.1 percent between 1993 and 1997, and in this case DOE and NSF support also declined while NASA and NIH support increased (see Table A-11).

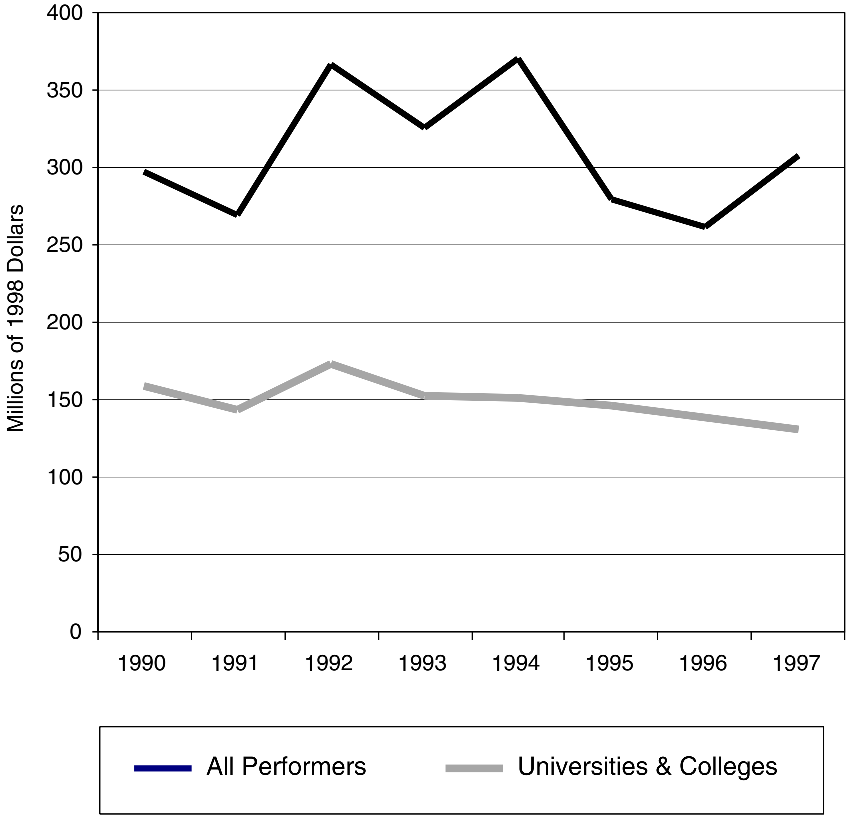



**FIGURE A-4** Constant dollar trends in federal funding of mathematics research, FY 1990–1997.
Source: Tables A-10 and A-11.

**TABLE A-10** Federal Obligations for Mathematics Research (basic and applied), by All Performers, by Field and Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 13.1 | 14.1 | 15.2 | 14.7 | 16.7 | 16.4 | 14.9 | 14.4 | -0.3 | -1.7 |
| Commerce | 8.6 | 13.4 | 14.3 | 13.7 | 13.4 | 13.5 | 14.0 | 10.7 | -2.9 | -21.5 |
| DOD | 77.2 | 50.2 | 99.6 | 90.6 | 98.4 | 111.9 | 97.4 | 46.2 | -44.4 | -49.0 |
| DOE | 37.9 | 43.8 | 73.0 | 77.2 | 89.5 | 0.5 | 0.0 | 88.4 | 11.2 | 14.5 |
| DHHS | 21.7 | 9.0 | 20.8 | 25.0 | 53.3 | 36.3 | 42.3 | 45.3 | 20.3 | 81.0 |
| *NIH* | *20.7* | *19.1* | *21.6* | *44.7* | *52.9* | *36.2* | *42.3* | *44.9* | *0.3* | *0.6* |
| Interior | 2.3 | 3.3 | 3.8 | 4.1 | 3.3 | 3.2 | 3.3 | 3.3 | -0.8 | -19.3 |
| EPA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 29.1 | 28.3 | 23.8 | 4.5 | 4.7 | 4.8 | 4.7 | 4.7 | 0.3 | 6.2 |
| NSF | 96.0 | 94.3 | 102.9 | 92.9 | 89.3 | 92.8 | 84.9 | 93.6 | 0.7 | 0.8 |
| All others | 11.7 | 12.8 | 12.6 | 2.8 | 2.1 | 0.2 | 0.2 | 0.6 | -2.2 | -78.0 |
| TOTAL | 297.7 | 269.1 | 366.1 | 325.4 | 370.6 | 279.6 | 261.7 | 307.3 | -18.1 | -5.6 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-11** Federal Obligations for University Mathematics Research (basic and applied), by Field and Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.4 | 1.0 | 0.8 | 0.7 | 0.5 | 0.6 | 0.3 | 0.2 | -0.5 | -70.8 |
| DOD | 45.1 | 30.5 | 45.9 | 44.4 | 49.0 | 41.5 | 35.8 | 20.6 | -23.8 | -53.5 |
| DOE | 21.2 | 19.3 | 17.4 | 8.5 | 9.9 | 0.0 | 0.0 | 7.4 | -1.0 | -12.3 |
| DHHS | 7.0 | 7.7 | 6.6 | 7.8 | 8.5 | 21.4 | 25.3 | 20.2 | 12.4 | 160.1 |
| *NIH* | *5.9* | *6.5* | *6.1* | *7.2* | *8.1* | *21.3* | *25.3* | *19.8* | *12.5* | *173.1* |
| NASA | 1.2 | 0.7 | 1.0 | 0.8 | 0.8 | 1.0 | 0.7 | 0.9 | 0.1 | 11.9 |
| NSF | 84.5 | 84.9 | 101.1 | 89.9 | 82.0 | 81.4 | 76.2 | 81.4 | -8.6 | -9.5 |
| TOTAL | 159.3 | 144.2 | 172.8 | 152.1 | 150.7 | 145.9 | 138.3 | 130.7 | -21.4 | -14.1 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Chemistry*

The base of support for chemistry is broad; six agencies provided between 5 and 30 percent of the funding each in 1993. The level of federal support for chemistry research was reduced by 8.7 percent between 1993 and 1997 in real terms (see Figure A-5 and Table A-12). Spending was down at DOD (by 26.6 percent), DOE (by 12.5 percent), DHHS/NIH (by 5.7 percent), and NSF (by 3.5 percent). There were increases at Commerce (27.1 percent), Interior (5.8 percent), and NASA (3.0 percent), but none were large in absolute terms. The pattern in federal support of university chemistry research was very similar (10.8

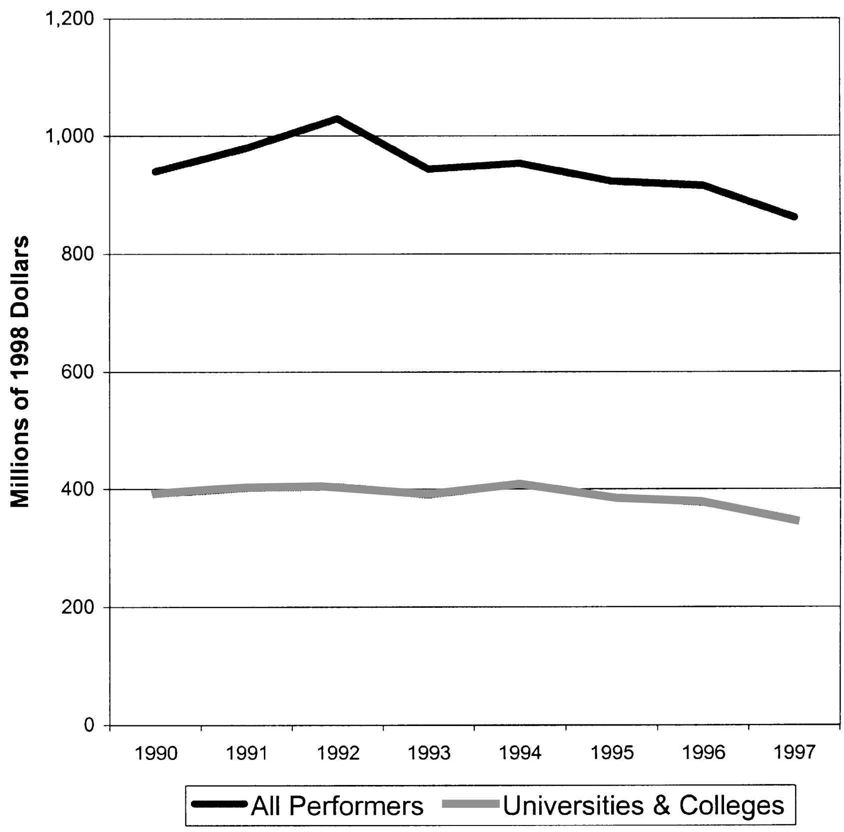



**FIGURE A-5** Constant dollar trends in federal funding of chemistry research, FY 1990–1997.
Source: Tables A-12 and A-13.

percent) (Table A-13). Holding NSF constant, because some research classified as chemistry in 1993 was apparently reclassified as "physical sciences, n.e.c" after 1995, reduces the federal cuts slightly, to 8.2 percent overall and 9.2 percent in university research.

**TABLE A-12** Federal Obligations for Chemistry Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 83.6 | 89.9 | 95.1 | 95.4 | 99.0 | 90.2 | 90.6 | 90.7 | -4.6 | -4.9 |
| Commerce | 30.8 | 32.1 | 34.0 | 34.7 | 40.3 | 46.3 | 49.0 | 44.1 | 9.4 | 27.1 |
| DOD | 149.2 | 163.8 | 156.9 | 156.5 | 160.5 | 154.6 | 110.8 | 114.9 | -41.7 | -26.6 |
| DOE | 233.3 | 221.9 | 251.9 | 275.7 | 246.5 | 230.9 | 278.1 | 241.4 | -34.3 | -12.5 |
| DHHS | 138.3 | 141.8 | 157.0 | 159.8 | 150.2 | 146.5 | 142.9 | 150.7 | -9.1 | -5.7 |
| *NIH* | *126.1* | *128.1* | *157.0* | *159.8* | *150.2* | *146.5* | *142.9* | *150.7* | *-9.1* | *-5.7* |
| Interior | 28.3 | 33.3 | 28.6 | 29.3 | 34.7 | 34.4 | 35.4 | 35.1 | 5.8 | 19.7 |
| EPA | 45.7 | 58.6 | 85.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 44.3 | 46.3 | 54.5 | 48.6 | 51.3 | 52.7 | 51.6 | 51.5 | 3.0 | 6.1 |
| NSF | 164.3 | 179.4 | 155.6 | 136.0 | 163.0 | 159.6 | 153.8 | 131.3 | -4.7 | -3.5 |
| All others | 21.5 | 12.5 | 9.9 | 7.7 | 7.9 | 7.7 | 3.0 | 1.8 | -5.9 | -76.1 |
| TOTAL | 939.4 | 979.6 | 1,029.5 | 943.7 | 953.4 | 923.0 | 915.3 | 861.5 | -82.2 | -8.7 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-13** Federal Obligations for University Research in Chemistry, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 17.8 | 22.0 | 26.9 | 28.4 | 32.0 | 26.5 | 22.5 | 26.7 | -1.7 | -5.9 |
| DOD | 51.6 | 49.0 | 58.5 | 59.9 | 60.0 | 67.1 | 63.1 | 40.2 | -19.7 | -32.8 |
| DOE | 55.1 | 47.2 | 50.9 | 56.8 | 48.8 | 45.9 | 49.7 | 46.4 | -10.4 | -18.4 |
| DHHS | 98.5 | 98.9 | 108.0 | 103.0 | 100.5 | 86.0 | 85.8 | 93.7 | -9.3 | -9.1 |
| *NIH* | *96.2* | *96.4* | *108.0* | *103.0* | *100.5* | *86.0* | *85.8* | *93.7* | *-9.3* | *-9.1* |
| NASA | 7.4 | 6.7 | 6.0 | 7.2 | 5.9 | 6.2 | 3.3 | 12.3 | 5.1 | 70.5 |
| NSF | 161.1 | 177.7 | 153.9 | 134.1 | 162.1 | 154.5 | 152.5 | 128.1 | -6.0 | -4.5 |
| TOTAL | 391.4 | 401.5 | 404.2 | 389.4 | 409.4 | 386.1 | 376.9 | 347.4 | -42.0 | -10.8 |

Notes: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Chemical Engineering*

Support of chemical engineering research is spread among a number of agencies: DOE (42 percent), DOD (28 percent), and NSF (16 percent). Between 1993 and 1997, DOD reduced its support substantially, and NSF also provided less support, in real terms (see Figure A-6 and Tables A-14 and A-15). Increases at a number of other agencies did not offset the declines. Federal spending on chemical engineering research was 12.9 percent less in 1997 than in 1993 in real terms. NSF's new classification procedures did not noticeably affect the level of NSF support of chemical engineering.

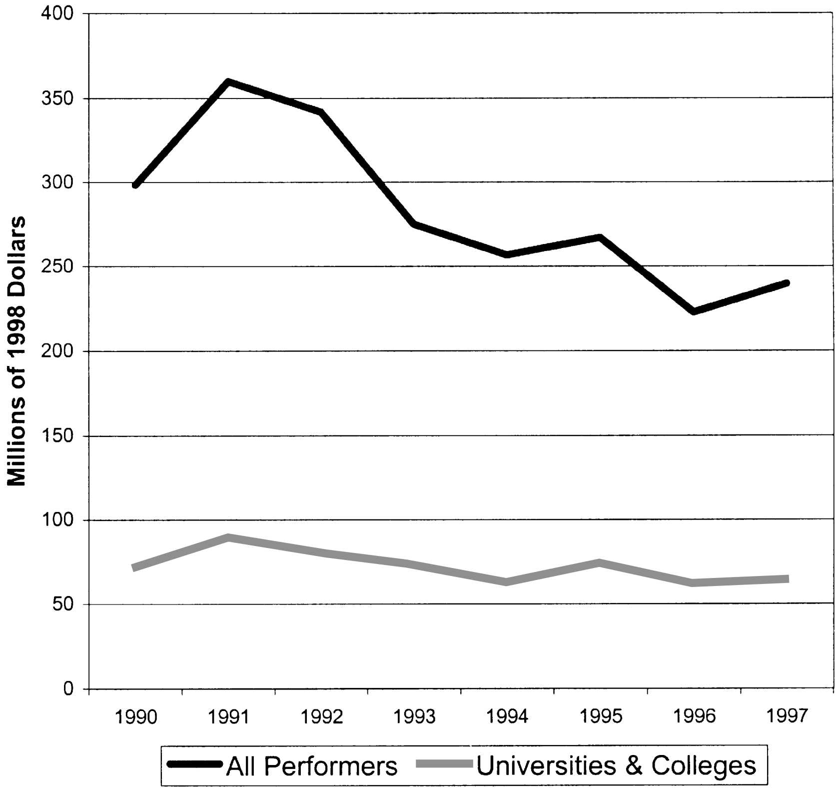



**FIGURE A-6** Constant dollar trends in federal funding of chemical engineering research, FY 1990–1997.
Source: Tables A-14 and A-15.

**TABLE A-14** Federal Obligations for Chemical Engineering Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 9.0 | 9.4 | 8.2 | 6.4 | 7.2 | 8.2 | 8.8 | 8.0 | 1.5 | 23.9 |
| Commerce | 4.8 | 5.4 | 5.5 | 8.1 | 6.2 | 12.8 | 14.2 | 20.1 | 12.0 | 148.0 |
| DOD | 46.1 | 49.5 | 39.8 | 78.2 | 38.1 | 45.6 | 43.0 | 30.9 | -47.3 | -60.5 |
| DOE | 130.6 | 168.2 | 155.2 | 116.0 | 143.4 | 129.4 | 96.2 | 121.6 | 5.6 | 4.9 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 7.2 | 8.4 | 10.3 | 9.8 | 13.8 | 13.1 | 12.9 | 13.4 | 3.6 | 36.7 |
| EPA | 30.2 | 37.1 | 51.4 | 2.8 | 2.9 | 2.8 | 2.6 | 2.7 | 0.0 | 0.0 |
| NASA | 17.6 | 15.2 | 15.3 | 3.0 | 3.1 | 3.2 | 3.2 | 3.2 | 0.2 | 6.7 |
| NSF | 44.3 | 58.2 | 52.3 | 43.3 | 36.7 | 49.2 | 40.6 | 39.6 | -3.8 | -8.7 |
| All others | 8.6 | 8.4 | 3.7 | 7.2 | 5.2 | 2.6 | 1.0 | 0.0 | -7.2 | -100.0 |
| TOTAL | 298.3 | 359.8 | 341.7 | 274.8 | 256.6 | 266.8 | 222.4 | 239.4 | -35.4 | -12.9 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-15** Federal Obligations for University Research in Chemical Engineering, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.1 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 |
| DOD | 1.7 | 2.2 | 3.5 | 7.8 | 1.3 | 5.1 | 5.3 | 6.3 | -1.6 | -19.9 |
| DOE | 28.2 | 30.9 | 28.2 | 24.7 | 22.4 | 21.1 | 14.8 | 16.6 | -8.1 | -32.9 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 2.6 | 2.5 | 1.9 | 2.7 | 3.0 | 3.2 | 1.9 | 1.8 | -0.9 | -33.6 |
| NSF | 39.6 | 51.7 | 46.5 | 37.9 | 35.5 | 44.5 | 39.6 | 39.0 | 1.0 | 2.7 |
| TOTAL | 72.2 | 89.3 | 80.1 | 73.2 | 62.3 | 73.9 | 61.6 | 63.9 | -9.3 | -12.7 |

Notes: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

### *Civil Engineering*

DOD support for civil engineering research by all performers declined 44.2 percent between 1993 and 1997, but this was almost entirely offset by increased support by NSF, the Department of Commerce, and other agencies, so that total funding was down only 0.4 percent. Nevertheless, 1993 funding of civil engineering research was low compared to previous and subsequent years, and the general trend in federal funding of civil engineering research has been down in the 1990s (Figure A-7 and Table A-16). As with chemical engineering, (and unlike mechanical engineering), NSF support of civil engineering was not noticeably affected by the advent of new classification procedures in 1996.

For university research in civil engineering, a nearly 30 percent increase by NSF more than offset reduced DOD support, so that funding was up 8.8 percent overall between 1993 and 1997 (see Table A-17).

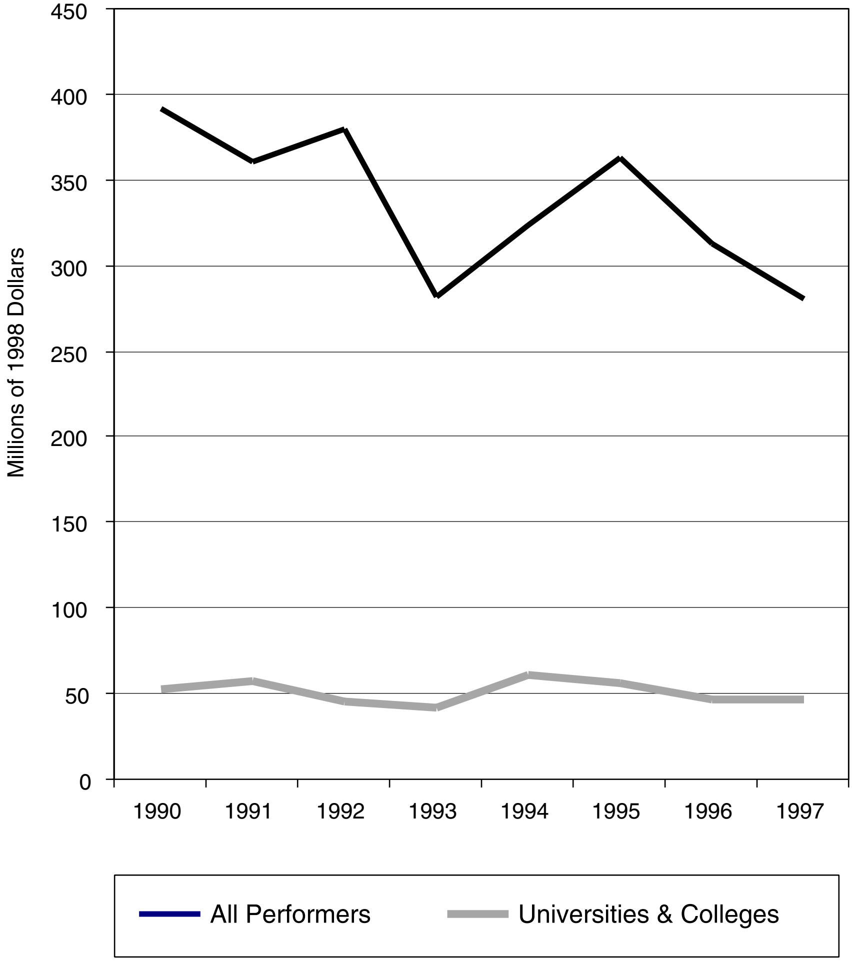



**FIGURE A-7** Constant dollar trends in federal funding of civil engineering research, FY 1990–1997.
Source: Tables A-16 and A-17.

**TABLE A-16** Federal Obligations for Civil Engineering Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 7.6 | 7.6 | 5.9 | 6.0 | 7.0 | 6.4 | 5.6 | 5.1 | -0.9 | -15.0 |
| Commerce | 7.2 | 6.2 | 5.2 | 6.7 | 9.5 | 14.0 | 11.8 | 14.4 | 7.8 | 116.4 |
| DOD | 202.2 | 190.2 | 211.3 | 111.1 | 109.0 | 89.4 | 62.1 | 62.0 | -49.1 | -44.2 |
| DOE | 32.8 | 38.2 | 29.3 | 36.1 | 39.9 | 56.2 | 39.5 | 37.9 | 1.7 | 4.8 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 4.0 | 4.6 | 5.7 | 11.0 | 8.2 | 8.4 | 8.7 | 7.7 | -3.2 | -29.5 |
| EPA | 25.7 | 28.0 | 30.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 0.2 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.0 | 5.7 |
| NSF | 38.1 | 36.4 | 35.2 | 32.2 | 33.5 | 44.1 | 39.0 | 38.4 | 6.3 | 19.5 |
| All others | 74.1 | 49.0 | 55.7 | 78.8 | 116.7 | 144.1 | 145.6 | 115.0 | 36.2 | 46.0 |
| TOTAL | 391.8 | 360.6 | 379.4 | 282.0 | 324.0 | 362.8 | 312.6 | 280.8 | -1.2 | -0.4 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-17** Federal Obligations for University Research in Civil Engineering, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 |
| DOD | 14.5 | 20.0 | 10.7 | 10.1 | 28.5 | 10.8 | 6.0 | 5.7 | -4.4 | -43.6 |
| DOE | 3.0 | 3.6 | 2.9 | 3.4 | 1.7 | 4.7 | 3.6 | 3.2 | -0.2 | -5.8 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 0.2 | 0.4 | 0.2 | 0.2 | 1.4 | 1.3 | 0.2 | 0.2 | 0.0 | 5.7 |
| NSF | 35.2 | 31.9 | 32.0 | 28.5 | 29.4 | 39.3 | 37.0 | 36.8 | 8.3 | 29.0 |
| TOTAL | 52.9 | 56.9 | 45.7 | 42.2 | 61.0 | 56.2 | 46.8 | 46.0 | 3.7 | 8.8 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

### *Geology*

Another field with support spread among a number of agencies (five accounted for between 10 and 33 percent each in 1993), geology experienced a 21.1 percent real drop in federal research spending between 1993 and 1997 (see Figure A-8 and Table A-18). The Department of the Interior, the largest funder, and NASA increased their levels of support during the period, by 3.8 and 6.2 percent, respectively. NSF joined DOD, DOE, and EPA in providing less support—33.6, 86.9, 55.2, and 26.0 percent, respectively. The NSF drop was probably due in part to the 1996 change in classification procedures. If NSF funding were held constant, the overall federal drop in support would be closer to 15 percent.

Federal spending on university geology research was 40.0 percent less in 1997 than in 1993 in real terms, as every agency involved in geology research that was surveyed reduced its level of support (see Table A-19). It should be noted, however, that the Department of the Interior is not surveyed for spending on university research and that the Interior Department accounts for more than two-fifths of the overall federal investment in geology research (see Table A-18). Presumably if the Interior Department numbers were included, the drop in federal

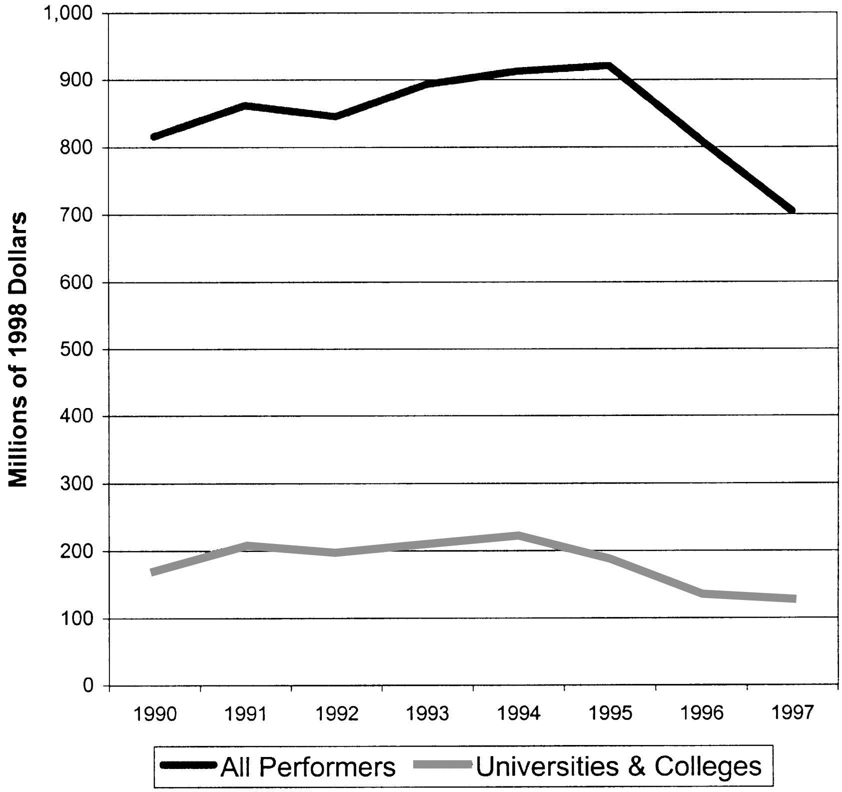



**FIGURE A-8** Constant dollar trends in federal funding of geology research, FY 1990–1997.
Source: Tables A-18 and A-19.

support of university geology research would be reduced, even though the U.S. Geological Survey has a relatively small extramural research program. At least some of the decrease in NSF support probably stems from the 1996 change in classification. If NSF were held constant, the overall decrease in federal funding of university geology would be closer to 27 percent.

**TABLE A-18** Federal Obligations for Geological Sciences Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 10.7 | 11.4 | 1.6 | 1.5 | 1.9 | 1.7 | 1.6 | 1.4 | -0.1 | -8.4 |
| Commerce | 6.2 | 9.2 | 4.9 | 6.7 | 4.8 | 46.5 | 38.4 | 4.2 | -2.5 | -37.3 |
| DOD | 118.1 | 102.0 | 86.0 | 94.5 | 100.8 | 83.2 | 54.4 | 12.3 | -82.1 | -86.9 |
| DOE | 123.1 | 106.8 | 86.5 | 130.6 | 89.2 | 106.8 | 93.4 | 58.5 | -72.2 | -55.2 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 277.7 | 301.5 | 302.2 | 293.0 | 322.7 | 296.3 | 308.6 | 304.2 | 11.3 | 3.8 |
| EPA | 7.1 | 8.6 | 5.8 | 15.7 | 16.4 | 11.9 | 11.0 | 11.6 | -4.1 | -26.0 |
| NASA | 126.9 | 156.9 | 189.5 | 193.0 | 204.0 | 209.5 | 205.3 | 204.9 | 11.9 | 6.2 |
| NSF | 133.8 | 157.9 | 161.2 | 153.3 | 165.8 | 159.4 | 91.7 | 101.7 | -51.6 | -33.6 |
| All others | 11.7 | 7.4 | 7.4 | 4.6 | 7.2 | 5.5 | 5.4 | 6.0 | 1.4 | 30.2 |
| TOTAL | 815.4 | 861.7 | 845.1 | 893.0 | 912.7 | 920.8 | 810.0 | 704.9 | -188.1 | -21.1 |

Note: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-19** Federal Obligations for University Research in Geological Sciences, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.5 | 0.9 | 0.5 | 1.2 | 0.7 | 1.0 | 0.3 | 0.5 | -0.7 | -62.2 |
| DOD | 44.2 | 45.4 | 36.0 | 44.0 | 60.4 | 31.6 | 16.3 | 6.4 | -37.6 | -85.4 |
| DOE | 29.9 | 23.8 | 20.6 | 29.8 | 18.4 | 25.6 | 26.4 | 21.3 | -8.6 | -28.7 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 21.0 | 23.3 | 22.4 | 25.2 | 22.1 | 20.2 | 17.9 | 15.4 | -9.8 | -39.0 |
| NSF | 75.0 | 115.5 | 116.8 | 110.8 | 120.7 | 108.3 | 74.0 | 83.1 | -27.7 | -25.0 |
| TOTAL | 170.6 | 208.9 | 196.3 | 211.0 | 222.2 | 186.7 | 134.9 | 126.5 | -84.4 | -40.0 |

Notes: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

## Fields with Increasing Support

As might be expected, the fields of biological and medical sciences benefited from the 10.9 percent real growth in the National Institutes of Health between 1993 and 1997, although to very different degrees. Aeronautical engineering benefited from the modest growth in NASA's research budget, especially from 1996 to 1997, but university research was reduced in contrast to the pattern in most other fields. Contrary to trends in the research budgets of the dominant funding agencies, however, the fields of computer sciences and materials engineering showed significant growth in federal support. Oceanography, the only other field showing substantial growth, is supported by several agencies.

### *Biological Sciences*

DHHS, led by NIH, funded 82 percent of the biological sciences in 1993. NIH funding of the biological sciences was $4.5 billion in 1997, 2.1 percent more than in 1993 in real terms (see Figure A-9 and Table A-20). There were increases

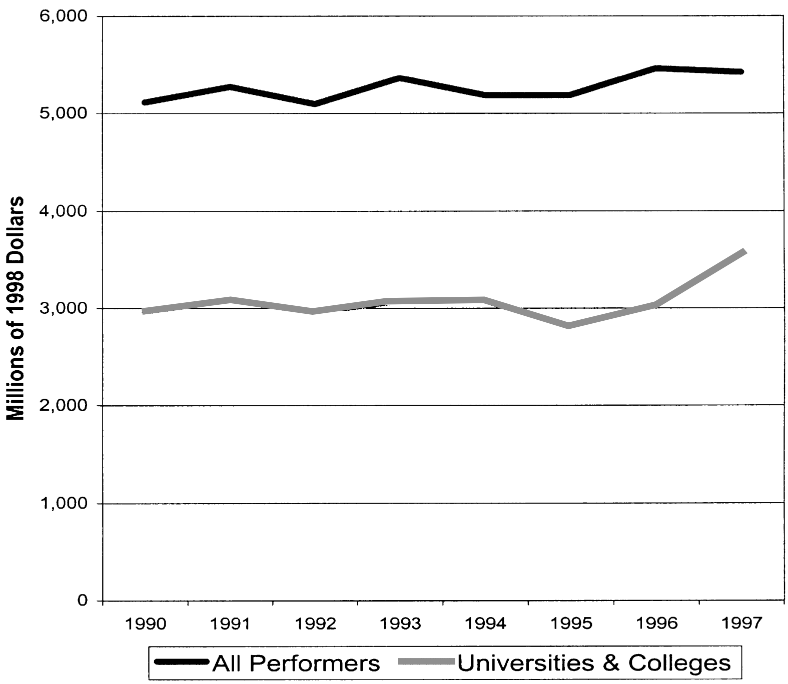



**FIGURE A-9** Constant-dollar trends in federal funding of biology research, FY 1990–1997.
Source: Tables A-20 and A-21.

**TABLE A-20** Federal Obligations for Biological Sciences Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | | | | | | | | | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Amount | Percent |
| USDA | 143.6 | 168.0 | 156.7 | 161.5 | 145.5 | 138.7 | 124.1 | 149.3 | -12.2 | -7.6 |
| Commerce | 0.0 | 12.1 | 26.4 | 18.6 | 24.7 | 40.4 | 60.6 | 25.3 | 6.7 | 36.1 |
| DOD | 72.4 | 78.3 | 82.7 | 96.8 | 58.5 | 68.8 | 56.1 | 67.1 | -29.7 | -30.7 |
| DOE | 196.6 | 179.4 | 187.2 | 202.2 | 184.9 | 211.9 | 194.9 | 165.8 | -36.4 | -18.0 |
| DHHS | 4,194.3 | 4,309.2 | 4,095.2 | 4,415.8 | 4,246.1 | 4,201.7 | 4,522.8 | 4,513.6 | 97.8 | 2.2 |
| *NIH* | *3,776.2* | *3,780.3* | *3,951.9* | *4,264.4* | *4,077.5* | *4,039.2* | *4,357.6* | *4,352.0* | *87.6* | *2.1* |
| Interior | 64.4 | 56.3 | 56.1 | 52.9 | 89.0 | 81.1 | 72.9 | 77.3 | 24.4 | 46.1 |
| EPA | 91.0 | 110.6 | 120.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 59.4 | 73.2 | 63.8 | 114.2 | 120.7 | 124.0 | 112.9 | 115.3 | 1.1 | 0.9 |
| NSF | 229.3 | 219.1 | 251.0 | 239.9 | 252.9 | 257.4 | 251.6 | 244.9 | 5.0 | 2.1 |
| All others | 60.9 | 64.9 | 55.3 | 58.8 | 62.7 | 60.9 | 63.4 | 62.3 | 3.5 | 6.0 |
| TOTAL | 5,111.8 | 5,271.1 | 5,094.8 | 5,360.8 | 5,185.0 | 5,184.9 | 5,459.4 | 5,421.0 | 60.2 | 1.1 |

Notes: The biological sciences include anatomy, biochemistry, biology, biometry and biostatistics, biophysics, botany, cell biology, entomology and parasitology, genetics, microbiology, neuroscience (biological), nutrition, physiology, zoology, and other biological disciplines. It excludes environmental and agricultural disciplines, which totaled about $147 million and $173 million, respectively, in FY 1997. Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

from much smaller bases at the Department of Commerce, NSF, NASA, and the Department of the Interior, which were more than offset by declines at DOD and USDA. The net increase in federal support for biological sciences was 1.1 percent between 1993 and 1997 in real terms.

Federal funding of university biological sciences research fared better. It was 16.1 percent larger in 1997 than in 1993 in real terms (see Table A-21). The increase in NIH funding accounted for nearly all of the increase. There were small increases at NASA, NSF, and DOD, which were more than offset by a drop in DOE support.

*Medical Sciences*

DHHS, again led by NIH, provided 84 percent of the support for research in the medical sciences in 1993. NIH increased its level of support for medical research by 19.4 percent between 1993 and 1997 (see Figure A-10 and Table A-22). Although several other agencies decreased their levels of support, especially DOD and the Department of Veterans Affairs (included in "All others"), there was a net increase in federal funding of medical sciences research of 14.4 percent between 1993 and 1997 in real terms.

**TABLE A-21** Federal Obligations for University Research in Biological Sciences, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 92.5 | 93.4 | 105.5 | 112.9 | 94.1 | 93.6 | 75.1 | 91.1 | -21.8 | -19.3 |
| DOD | 26.9 | 33.6 | 36.6 | 36.8 | 31.8 | 28.0 | 28.6 | 38.5 | 1.7 | 4.7 |
| DOE | 46.4 | 54.8 | 59.6 | 62.5 | 60.3 | 60.3 | 58.5 | 42.9 | -19.6 | -31.3 |
| DHHS | 2,599.1 | 2,684.8 | 2,520.4 | 2,623.6 | 2,648.7 | 2,382.8 | 2,624.3 | 3,148.6 | 525.1 | 20.0 |
| *NIH* | *2,380.8* | *2,422.3* | *2,515.2* | *2,615.7* | *2,637.7* | *2,372.3* | *2,613.6* | *3,137.2* | *521.5* | *19.9* |
| NASA | 17.0 | 23.2 | 21.9 | 21.2 | 19.0 | 25.3 | 30.2 | 27.0 | 5.7 | 27.0 |
| NSF | 186.6 | 197.1 | 216.9 | 215.7 | 222.5 | 220.6 | 217.3 | 218.8 | 3.1 | 1.4 |
| TOTAL | 2,968.5 | 3,086.9 | 2,960.9 | 3,072.7 | 3,076.5 | 2,810.5 | 3,034.0 | 3,566.9 | 494.2 | 16.1 |

Notes: The biological sciences include anatomy, biochemistry, biology, biometry and biostatistics, biophysics, botany, cell biology, entomology and parasitology, genetics, microbiology, neuroscience (biological), nutrition, physiology, zoology, and other biological disciplines. It excludes environmental and agricultural disciplines, which totaled about $147 million and $173 million respectively in FY 1997. Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

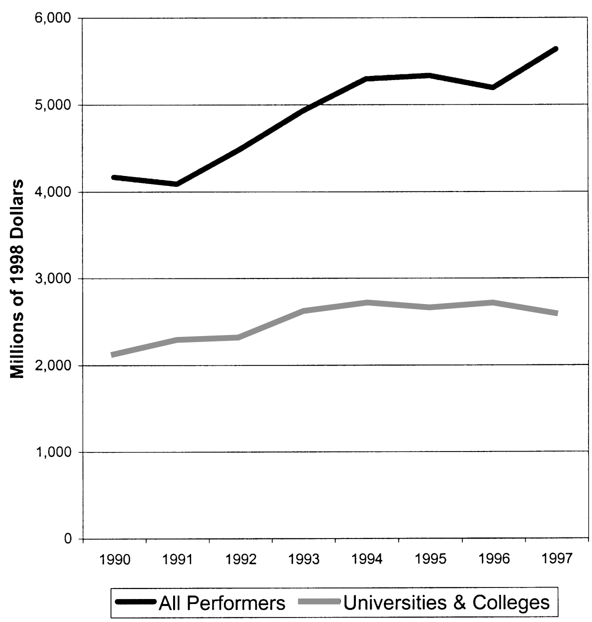



**FIGURE A-10** Constant dollar trends in federal funding of medical research, FY 1990–1997.
Source: Tables A-22 and A-23.

**TABLE A-22** Federal Obligations for Medical Sciences Research, All Performers, by Agency, FY 1990–1997 (millions of dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 30.3 | 25.9 | 33.6 | 32.9 | 32.6 | 29.4 | 25.8 | 23.7 | -9.2 | -27.9 |
| Commerce | 1.7 | 3.1 | 1.9 | 4.9 | 5.2 | 20.5 | 17.5 | 22.0 | 17.1 | 352.4 |
| DOD | 204.8 | 212.3 | 253.8 | 249.1 | 231.8 | 253.5 | 175.4 | 174.7 | -74.4 | -29.9 |
| DOE | 45.5 | 136.7 | 142.6 | 54.7 | 77.4 | 50.5 | 47.1 | 53.3 | -1.5 | -2.7 |
| DHHS | 3,537.6 | 3,393.5 | 3,677.8 | 4,115.9 | 4,531.5 | 4,639.2 | 4,585.9 | 5,030.2 | 914.3 | 22.2 |
| *NIH* | *3,115.1* | *3,007.8* | *3,467.6* | *3,886.9* | *4,251.3* | *4,238.3* | *4,225.5* | *4,641.7* | *754.9* | *19.4* |
| Interior | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| EPA | 23.3 | 13.3 | 15.4 | 19.2 | 20.1 | 22.4 | 20.8 | 21.9 | 2.7 | 14.0 |
| NASA | 64.2 | 84.0 | 72.6 | 116.4 | 123.0 | 126.4 | 112.2 | 123.6 | 7.2 | 6.2 |
| NSF | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| All others | 264.3 | 222.9 | 294.1 | 336.3 | 275.0 | 190.6 | 209.3 | 188.2 | -148.1 | -44.0 |
| TOTAL | 4,171.6 | 4,091.6 | 4,491.6 | 4,929.4 | 5,296.7 | 5,332.5 | 5,194.0 | 5,637.6 | 708.2 | 14.4 |

Notes: The medical sciences include dentistry, internal medicine, neurology, obstetrics and gynecology, ophthalmology otolaryngology, pathology, pediatrics, pharmacology, pharmacy, preventive medicine, psychiatry, radiology, surgery, veterinary medicine, and other medical disciplines. Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

The annual level of federal funding of university medical research fell by 1.1 percent in real terms between 1993 and 1996 (see Table A-23). Increased support by DOD (9.0 percent) and DOE (99.5 percent) (the latter two from small bases) was more than offset by decreases at NIH and NASA.

### *Aeronautical Engineering*

NASA accounted for 81 percent of the federal support for aeronautical engineering research in 1993 (DOD supported most of the rest). NASA's total budget for research was 7.4 percent more in 1997 than in 1993, and it increased aeronautical engineering research by 6.1 percent (see Figure A-11 and Table A-24). Nevertheless, the increase occurred in a single year, 1997. Previously, NASA's funding of aeronautical engineering was falling. Several other agencies reduced support, especially DOD, and the field grew by only 3.2 percent overall. If the elimination of NSF support was only apparent, because the research was reclassified as "engineering, n.e.c.," aeronautical research would have increased slightly more (by 3.5 percent if NSF support is held constant).

In contrast with many other fields, however, university research was not protected. University aeronautics was cut 13.9 percent in real terms between 1993

**TABLE A-23** Federal Obligations for University Research in Medical Sciences Research, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 17.1 | 11.5 | 10.8 | 11.5 | 11.6 | 9.8 | 9.3 | 8.4 | -3.1 | -26.5 |
| DOD | 25.6 | 23.5 | 49.5 | 47.2 | 50.4 | 43.6 | 61.3 | 51.4 | 4.2 | 9.0 |
| DOE | 14.3 | 85.8 | 60.0 | 15.3 | 30.1 | 26.8 | 17.9 | 30.5 | 15.2 | 99.5 |
| DHHS | 2,067.3 | 2,154.2 | 2,197.6 | 2,532.2 | 2,623.6 | 2,566.1 | 2,609.0 | 2,489.7 | -42.5 | -1.7 |
| *NIH* | *1,891.5* | *1,977.9* | *2,127.2* | *2,454.6* | *2,554.2* | *2,488.9* | *2,534.6* | *2,404.3* | *-50.3* | *-2.1* |
| NASA | 7.7 | 6.7 | 6.9 | 8.8 | 8.1 | 10.3 | 7.5 | 5.4 | -3.4 | -38.6 |
| NSF | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| TOTAL | 2,132.0 | 2,281.7 | 2,324.9 | 2,614.9 | 2,723.7 | 2,656.6 | 2,704.9 | 2,585.4 | -29.5 | -1.1 |

Notes: The Medical include dentistry, internal medicine, neurology, obstetrics and gynecology, ophthalmology, otolaryngology, pathology, pediatrics, pharmacology, pharmacy, preventive medicine, psychiatry, radiology, surgery, veterinary medicine, and other medical disciplines. Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

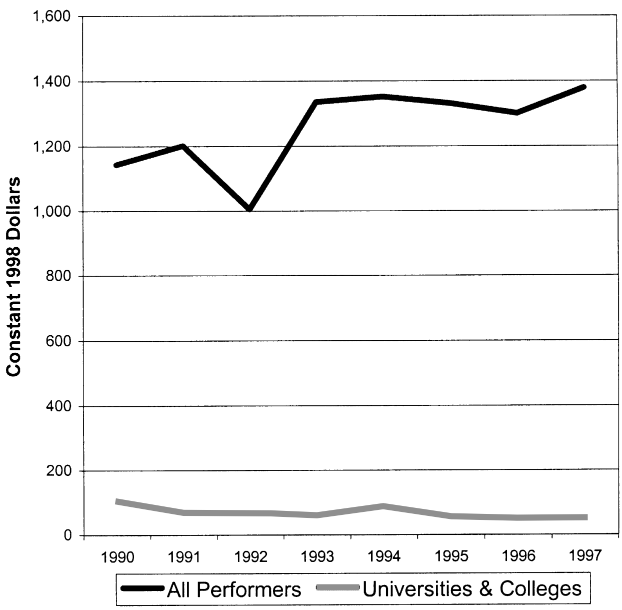



**FIGURE A-11** Constant dollar trends in federal funding of aeronautical engineering research, FY 1990–1997.
Source: Tables A-24 and A-25.

and 1997 (see Table A-25). However, the amount of funding going to universities was small to begin with, $52 million in 1993, just 4.4 percent of all federally funded aeronautical engineering research. Also, if NSF support were held constant, the cut would be less (8.7 percent).

**TABLE A-24** Federal Obligations for Aeronautical Engineering Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Commerce | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 293.1 | 265.3 | 186.1 | 243.9 | 198.0 | 149.8 | 236.0 | 224.5 | -19.4 | -8.0 |
| DOE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| EPA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 844.4 | 932.0 | 814.3 | 1,087.3 | 1,149.1 | 1,180.3 | 1,064.5 | 1,153.8 | 66.5 | 6.1 |
| NSF | 0.8 | 1.0 | 3.4 | 3.7 | 3.6 | 0.0 | 0.0 | 0.0 | -3.7 | -100.0 |
| All others | 5.2 | 3.4 | 0.9 | 0.3 | 0.3 | 0.3 | 0.0 | 0.0 | -0.3 | -100.0 |
| TOTAL | 1,143.4 | 1,201.6 | 1,004.7 | 1,335.2 | 1,351.0 | 1,330.4 | 1,300.5 | 1,378.4 | 43.1 | 3.2 |

Note: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-25** Federal Obligations for University Research in Aeronautical Engineering, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 49.4 | 24.3 | 27.7 | 21.2 | 43.8 | 22.2 | 22.4 | 15.3 | -5.9 | -27.9 |
| DOE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 53.5 | 43.7 | 34.3 | 34.1 | 39.9 | 33.6 | 26.5 | 35.0 | 0.8 | 2.4 |
| NSF | 0.8 | 0.9 | 3.4 | 3.0 | 0.2 | 0.0 | 0.0 | 0.0 | -3.0 | -100.0 |
| TOTAL | 103.7 | 68.9 | 65.4 | 58.3 | 83.9 | 55.9 | 48.9 | 50.3 | -8.1 | -13.9 |

Notes: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Computer Science*

Not all research fields in which DOD is the main funder experienced decreased federal funding. One of these exceptions was computer sciences, for which DOD provided 57 percent of the federal support in 1993. DOD support fell between 1993 and 1997 but by less than 1 percent (Figure A-12 and Table A-26). But due to increases at several other agencies, total federal support of computer science research increased more than 39 percent in real terms. In absolute terms there were substantial increases in computer science funding at NSF and DOE in 1996, as well as smaller increases at the Department of Commerce and DHHS. This growth may have been driven in part by the interagency high-performance computing and communications initiative of the National Science and Technology Council. The increase in computer science research funding by DOE in 1996 was due to a large increase in computing by DOE's atomic weapons program. The large increase in NSF support appears to be real and not an artifact of changed classification procedures. The level of NSF support of mathematics and of "mathematics & computer sciences, n.e.c." did not change substantially from 1995 to 1996.

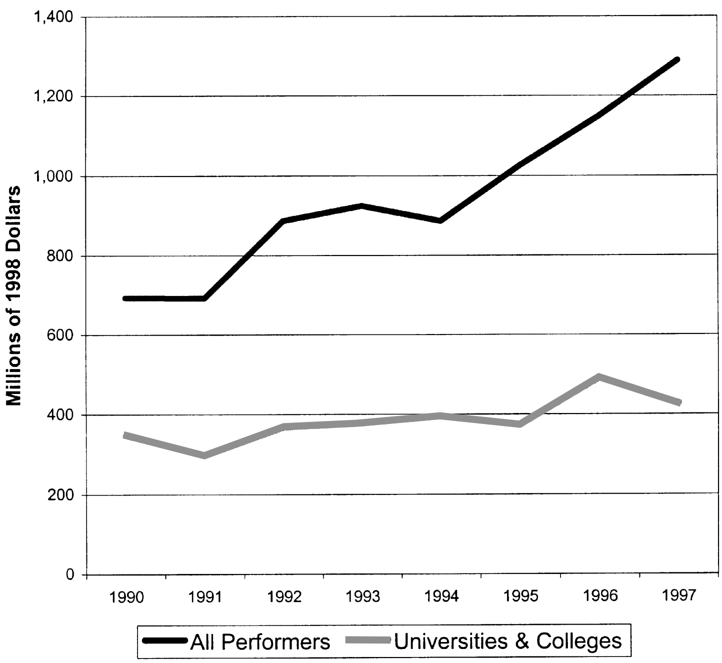



**FIGURE A-12** Constant-dollar trends in federal funding of computer sciences research, FY 1990–1997.
Source: Tables A-26 and A-27.

DOD also reduced slightly its support of university research in computer sciences between 1993 and 1997, from $210 million to $204 million or by 2.9 percent (see Table A-27). In fact, university computer science funding increased by 13.0 percent in real terms, with NSF accounting for nearly all of the increase. But if the NSF increase is all or mostly due to changes in the classification and reporting of ongoing activities, the increase might actually have been much smaller.

**TABLE A-26** Federal Obligations for Computer Sciences Research All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | | | | | | | | | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Amount | Percent |
| USDA | 1.7 | 1.7 | 2.9 | 2.6 | 2.8 | 2.7 | 2.2 | 0.0 | -2.6 | -100.0 |
| Commerce | 6.1 | 15.9 | 22.4 | 26.1 | 35.0 | 89.3 | 60.0 | 61.2 | 35.2 | 134.8 |
| DOD | 438.1 | 341.2 | 491.3 | 529.4 | 497.7 | 578.7 | 493.9 | 533.5 | 4.1 | 0.8 |
| DOE | 28.1 | 103.2 | 133.6 | 115.7 | 97.9 | 103.5 | 209.3 | 324.6 | 208.9 | 180.5 |
| DHHS | 1.6 | 1.1 | 1.9 | 23.7 | 14.5 | 37.1 | 55.9 | 59.6 | 35.9 | 151.5 |
| *NIH* | *0.2* | *0.0* | *1.8* | *20.1* | *0.9* | *25.8* | *45.7* | *51.5* | *31.4* | *156.1* |
| Interior | 12.5 | 14.5 | 11.9 | 12.1 | 15.2 | 14.7 | 14.7 | 15.7 | 3.5 | 29.2 |
| EPA | 5.2 | 5.3 | 6.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 55.8 | 60.4 | 50.3 | 26.7 | 28.2 | 29.0 | 27.4 | 28.2 | 1.4 | 5.4 |
| NSF | 134.5 | 125.6 | 141.5 | 142.1 | 159.0 | 132.2 | 255.6 | 246.1 | 103.9 | 73.1 |
| All others | 9.6 | 22.8 | 24.2 | 46.1 | 35.9 | 37.7 | 29.6 | 19.9 | -26.2 | -56.9 |
| TOTAL | 693.3 | 691.7 | 886.6 | 924.5 | 886.3 | 1,024.9 | 1,148.6 | 1,288.6 | 364.1 | 39.4 |

Note: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-27** Federal Obligations for University Research in Computer Sciences, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | | | | | | | | | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Amount | Percent |
| USDA | 0.1 | 1.1 | 2.7 | 2.3 | 2.7 | 2.1 | 2.2 | 0.0 | -2.3 | -100.0 |
| DOD | 193.7 | 157.8 | 204.1 | 210.3 | 216.8 | 226.4 | 237.0 | 204.3 | -6.0 | -2.9 |
| DOE | 4.0 | 4.6 | 4.6 | 5.1 | 2.5 | 4.6 | 4.3 | 2.4 | -2.7 | -52.8 |
| DHHS | 0.4 | 0.4 | 0.0 | 0.9 | 2.5 | 17.9 | 28.8 | 1.8 | 0.9 | 95.3 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.2* | *15.1* | *27.1* | *1.8* | *1.8* | *NA* |
| NASA | 29.3 | 25.8 | 20.9 | 21.4 | 18.3 | 23.7 | 22.6 | 17.6 | -3.8 | -17.7 |
| NSF | 120.2 | 107.9 | 135.2 | 137.9 | 152.0 | 99.1 | 196.3 | 201.0 | 63.0 | 45.7 |
| TOTAL | 347.7 | 297.6 | 367.5 | 378.1 | 394.8 | 373.9 | 491.1 | 427.2 | 49.1 | 13.0 |

Notes: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Materials Engineering*

Materials research, broadly defined, is an economically important area of research. NSF does not track the field, a relatively new one, but it does track funding for a major component, materials engineering. DOD is the dominant sponsor, providing 73 percent of federal funding in 1993. By 1997, DOD had reduced its annual commitment by 28 percent in real terms (see Figure A-13 and Table A-28). The Department of the Interior also reduced its support from about $25 million a year to zero when the Bureau of Mines was abolished. In this case, however, other agencies stepped up their support substantially, DOE by 275 percent, NSF by 356 percent, and the Department of Commerce by 85 percent (the latter two from small bases). As a result, real spending on materials engineering

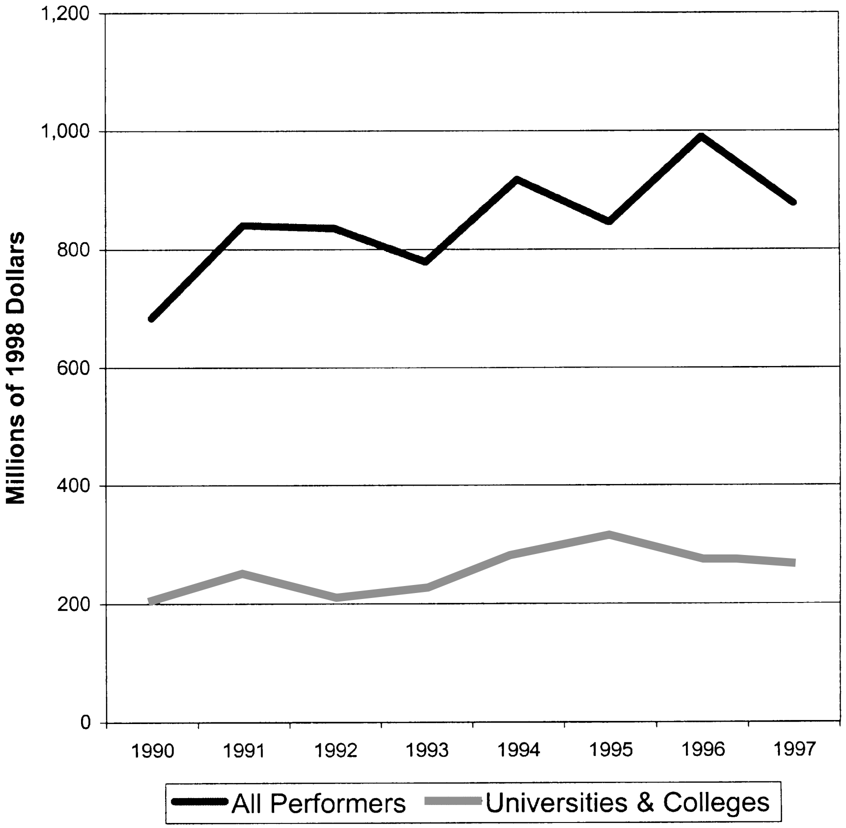



**FIGURE A-13** Constant-dollar trends in federal funding of materials engineering research, FY 1990–1997.
Source: Tables A-28 and A-29.

**TABLE A-28** Federal Obligations for Metallurgy & Materials Engineering Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Commerce | 14.6 | 17.6 | 23.1 | 26.2 | 30.1 | 60.6 | 70.4 | 48.5 | 22.2 | 84.8 |
| DOD | 457.0 | 583.1 | 599.2 | 570.8 | 524.3 | 495.2 | 480.0 | 410.7 | -160.1 | -28.0 |
| DOE | 96.8 | 86.2 | 77.1 | 74.9 | 78.4 | 67.8 | 274.7 | 281.1 | 206.2 | 275.1 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 30.9 | 29.7 | 32.0 | 27.4 | 95.1 | 0.1 | 0.3 | 0.1 | -27.3 | -99.5 |
| EPA | 0.9 | 0.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NASA | 73.8 | 87.8 | 77.4 | 46.7 | 49.3 | 50.7 | 49.6 | 19.3 | -27.4 | -58.6 |
| NSF | 9.7 | 34.2 | 25.2 | 23.9 | 129.5 | 159.7 | 109.4 | 108.9 | 85.0 | 355.8 |
| All others | 0.2 | 1.6 | 1.0 | 8.6 | 10.2 | 11.3 | 5.2 | 8.4 | -0.3 | -3.2 |
| TOTAL | 683.9 | 840.3 | 835.4 | 778.6 | 917.0 | 845.3 | 989.6 | 877.0 | 98.4 | 12.6 |

Note: Constant-dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1).
Source: National Science Foundation (1998b).

research was 12.6 percent greater in 1997 than in 1993 and the field had a broader base of support among the agencies.

The DOE increase began suddenly in 1996, when its spending on materials engineering tripled to $264 million, and may reflect a recategorization of existing activities, not a real increase. If the DOE increase were ignored, the field may not have experienced a real increase at all. On the other hand, the general level of NSF funding was lower after 1995 by about $40 million, indicating that materials engineering was affected by the 1996 change in classification procedures at NSF. If so, real federal funding of materials engineering research was greater than the survey indicates, offsetting the DOE changes.

Federal funding of university research in materials engineering increased 18.6 percent in real terms between 1993 and 1997 (see Table A-29). DOD's contribution was down by 28.6 percent compared with 1993 in real terms. Despite the huge increase in overall support for the field beginning in 1996, DOE's support of university research was much less—5.6 percent. The net increase in support came from a substantial increase in funding by NSF—372 percent from 1993 to 1997 in real terms. The increase may have been larger, because the 1996 change in classification procedures at NSF shifted at least some work from the materials engineering category to "engineering, n.e.c."

**TABLE A-29** Federal Obligations for University Research in Metallurgy & Materials Engineering, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 146.5 | 170.8 | 140.7 | 154.4 | 117.6 | 120.7 | 132.8 | 121.0 | -33.4 | -21.6 |
| DOE | 25.9 | 25.7 | 23.5 | 24.0 | 21.4 | 19.5 | 21.6 | 25.4 | 1.3 | 5.6 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 23.4 | 24.0 | 22.3 | 23.3 | 18.2 | 20.5 | 13.4 | 12.4 | -10.9 | -46.9 |
| NSF | 8.5 | 32.3 | 24.2 | 22.8 | 127.7 | 154.0 | 108.6 | 107.4 | 84.6 | 371.9 |
| TOTAL | 204.2 | 252.8 | 210.7 | 224.5 | 284.9 | 314.7 | 276.4 | 266.2 | 41.7 | 18.6 |

Notes: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

*Oceanography*

Oceanography research receives most of its federal support from five agencies: Department of Commerce (32 percent), NASA (23 percent), DOD (19 percent), NSF (17 percent), and Department of the Interior (8 percent) (in 1993). Total federal funding was 16.4 percent greater in 1997 than in 1993 in real terms (see Figure A-14 and Table A-30). Federal spending levels fell at Commerce and Interior, by 17.8 and 68.8 percent, respectively. DOD increased its level of support substantially, by 23.8 percent. NSF more than doubled its level of spending on oceanography beginning in 1996, which accounted for more than the net increase. As noted above, however, NSF changed its procedures for classifying research by field in 1996. Although NSF support for environmental sciences overall was about the same in 1995 and 1996, there were sudden decreases in the levels of support for atmospheric and geological sciences and in "environmental sciences, n.e.c." that equaled the sudden jump in the level of oceanography research that year. If NSF funding of oceanography had stayed about even in real terms, federal support for oceanography research would have increased only by a few percent.

A similar pattern held in federal support of university research in oceanography. It was 36.6 percent larger in 1997 than in 1993 in real terms (see Table A-31). Again, a substantial jump in NSF spending beginning in 1996 accounted for all of the net increase, and most or all of that increase may be due to changes in how NSF categorizes research by field. Support from the other agencies was

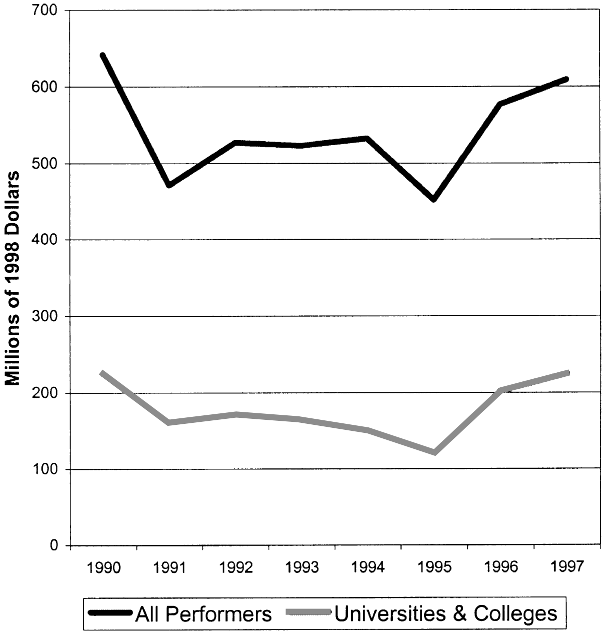



**FIGURE A-14** Constant-dollar trends in federal funding of oceanography research, FY 1990–1997.
Source: Tables A-30 and A-31.

**TABLE A-30** Federal Obligations for Oceanography Research, All Performers, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | | | | | | | | | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Amount | Percent |
| USDA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Commerce | 188.5 | 115.8 | 160.5 | 165.1 | 209.8 | 102.2 | 109.3 | 135.7 | -29.4 | -17.8 |
| DOD | 93.1 | 102.4 | 97.3 | 97.0 | 86.2 | 111.7 | 122.0 | 120.1 | 23.1 | 23.8 |
| DOE | 7.4 | 5.9 | 7.1 | 8.4 | 8.0 | 8.7 | 12.1 | 7.4 | -1.0 | -11.7 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| Interior | 32.6 | 32.3 | 41.3 | 43.0 | 13.2 | 13.5 | 15.7 | 13.4 | -29.6 | -68.8 |
| EPA | 3.8 | 0.9 | 2.2 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | -0.5 | -100.0 |
| NASA | 81.5 | 121.4 | 124.2 | 120.3 | 127.1 | 130.6 | 127.9 | 127.7 | 7.4 | 6.2 |
| NSF | 232.2 | 89.3 | 91.6 | 87.2 | 86.5 | 84.1 | 188.7 | 203.5 | 116.3 | 133.4 |
| All others | 2.3 | 3.3 | 2.9 | 1.4 | 1.2 | 1.0 | 1.0 | 1.1 | -0.4 | -25.6 |
| TOTAL | 641.5 | 471.3 | 527.2 | 523.1 | 532.6 | 451.8 | 576.8 | 609.0 | 86.0 | 16.4 |

Note: Constant-dollar conversions were made using the GDP deflators in OMB (1998,Table 10.1).
Source: National Science Foundation (1998b).

**TABLE A-31** Federal Obligations for University Research in Oceanography, by Agency, FY 1990–1997 (millions of constant 1998 dollars)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Amount | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOD | 55.3 | 66.6 | 64.8 | 64.2 | 50.1 | 48.2 | 50.7 | 52.8 | -6.7 | -17.6 |
| DOE | 4.1 | 3.1 | 4.1 | 3.9 | 4.1 | 4.8 | 3.6 | 4.3 | 0.7 | 11.7 |
| DHHS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *NIH* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* | *0.0* |
| NASA | 10.8 | 10.7 | 18.4 | 14.0 | 14.5 | 13.8 | 11.5 | 12.2 | -0.8 | -12.9 |
| NSF | 154.3 | 79.9 | 84.2 | 82.2 | 82.6 | 54.4 | 136.1 | 155.0 | 76.8 | 88.6 |
| TOTAL | 224.4 | 160.3 | 171.5 | 164.2 | 151.3 | 121.1 | 201.9 | 224.3 | 70.0 | 36.6 |

Notes: Constant dollar conversions were made using the GDP deflators in OMB (1998, Table 10.1). Federal support for university research is reported for only six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
Source: National Science Foundation (1998b).

either about the same or reduced. Also, the size of the increase might be less if spending on university oceanography by the Department of the Interior, which reduced its overall support of oceanography research during the time period, were included.

## TRENDS IN GRADUATE ENROLLMENT

The NSF survey of the numbers of graduate students by source of support publishes most of the data by broad area of science and engineering, such as physical sciences or earth, atmospheric, and ocean sciences, rather than by academic field, such as physics and chemistry or geology and oceanography. The former categories are too general to associate changes in federal research funding with changes in graduate training by field. Table A-32 presents data on sources of federal support of full-time graduate students in science and engineering in all universities and colleges in five fields that correspond to the categories used above: computer science, biological sciences, chemical engineering, electrical engineering, and mechanical engineering.

The changes are mostly in the expected direction (see Table A-33). Where federal support of university research in a field was down sharply between 1993 and 1997 in real terms, graduate enrollments were generally down also. In chemical engineering, for example, federal funding of university research declined by nearly 13 percent between 1993 and 1997 in real terms (from Table A-15). The number of graduate students in chemical engineering also declined during the same period, by 5 percent (the number of graduate students whose main source of support was federal declined more) (Table A-32). In mechanical engineering,

**TABLE A-32** Full-Time Graduate Students in Science and Engineering, Doctoral Institutions, by Field and Agency of Support: 1990–1997 (number)

| Field and Source of Support | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 Number | Change, 1993–1997 Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| All S&E Fields | | | | | | | | | | |
| All federally supported | 51,706 | 55,166 | 57,326 | 59,469 | 59,788 | 58,539 | 57,094 | 55,902 | -3,567 | -6.0 |
| DOD | 8,425 | 8,640 | 8,753 | 9,220 | 8,951 | 8,834 | 8,317 | 8,568 | -652 | -7.1 |
| DHHS, total | 14,522 | 15,381 | 16,154 | 16,701 | 17,035 | 17,024 | 16,817 | 16,610 | -91 | -0.5 |
| NIH | 13,298 | 14,081 | 14,930 | 15,749 | 15,843 | 15,600 | 15,411 | 15,181 | -568 | -3.6 |
| NSF | 11,932 | 12,542 | 13,223 | 13,325 | 13,656 | 13,447 | 13,258 | 13,169 | -156 | -1.2 |
| USDA | 2,629 | 2,982 | 3,099 | 3,202 | 3,297 | 3,152 | 2,902 | 2,560 | -642 | -20.0 |
| Other federal | 14,198 | 15,621 | 16,097 | 17,021 | 16,849 | 16,082 | 15,800 | 14,995 | -2,026 | -11.9 |
| All nonfederally supported | 198,824 | 205,988 | 215,816 | 216,827 | 215,536 | 210,874 | 209,138 | 206,259 | -10,568 | -4.9 |
| Total, all sources of support | 250,530 | 261,154 | 273,142 | 276,296 | 275,324 | 269,413 | 266,232 | 262,161 | -14,135 | -5.1 |
| Computer Sciences | | | | | | | | | | |
| All federally supported | 2,376 | 2,501 | 2,595 | 2,883 | 3,007 | 3,109 | 3,074 | 3,114 | 231 | 8.0 |
| DOD | 1,127 | 1,125 | 1,171 | 1,314 | 1,311 | 1,390 | 1,335 | 1,411 | 97 | 7.4 |
| DHHS, total | 68 | 71 | 100 | 103 | 97 | 110 | 113 | 106 | 3 | 2.9 |
| NIH | 61 | 65 | 97 | 95 | 89 | 92 | 80 | 78 | -17 | -17.9 |
| NSF | 818 | 896 | 958 | 1,003 | 1,040 | 1,050 | 1,044 | 1,076 | 73 | 7.3 |
| USDA | 14 | 8 | 6 | 7 | 9 | 13 | 13 | 12 | 5 | 71.4 |
| Other federal | 349 | 401 | 360 | 456 | 550 | 546 | 569 | 509 | 53 | 11.6 |
| All nonfederally supported | 12,522 | 12,369 | 13,174 | 12,944 | 12,382 | 12,107 | 12,559 | 13,374 | 430 | 3.3 |
| Total, all sources of support | 14,898 | 14,870 | 15,769 | 15,827 | 15,389 | 15,216 | 15,633 | 16,488 | 661 | 4.2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Biological Sciences | | | | | | | | | | |
| All federally supported | 13,519 | 14,372 | 15,002 | 16,048 | 16,583 | 16,492 | 16,435 | 16,111 | 63 | 0.4 |
| DOD | 222 | 220 | 229 | 269 | 346 | 354 | 358 | 358 | 89 | 33.1 |
| DHHS, total | 9,908 | 10,616 | 10,989 | 11,554 | 11,927 | 12,004 | 11,819 | 11,723 | 169 | 1.5 |
| NIH | 9,542 | 10,164 | 10,575 | 11,236 | 11,412 | 11,332 | 11,230 | 11,141 | -95 | -0.8 |
| NSF | 1,201 | 1,269 | 1,333 | 1,362 | 1,369 | 1,399 | 1,484 | 1,518 | 156 | 11.5 |
| USDA | 960 | 1,060 | 1,078 | 1,215 | 1,280 | 1,078 | 1,065 | 921 | -294 | -24.2 |
| Other federal | 1,228 | 1,207 | 1,373 | 1,648 | 1,661 | 1,657 | 1,709 | 1,591 | -57 | -3.5 |
| All nonfederally supported | 26,076 | 26,910 | 27,830 | 28,611 | 29,627 | 29,943 | 29,402 | 28,953 | 342 | 1.2 |
| Total, all sources of support | 39,595 | 41,282 | 42,832 | 44,659 | 46,210 | 46,435 | 45,837 | 45,064 | 405 | 0.9 |
| Chemical Engineering | | | | | | | | | | |
| All federally supported | 1,528 | 1,592 | 1,643 | 1,735 | 1,706 | 1,740 | 1,769 | 1,622 | -113 | -6.5 |
| DOD | 98 | 134 | 123 | 138 | 128 | 164 | 166 | 158 | 20 | 14.5 |
| DHHS, total | 121 | 132 | 166 | 141 | 173 | 163 | 162 | 137 | -4 | -2.8 |
| NIH | 119 | 128 | 146 | 119 | 143 | 136 | 148 | 121 | 2 | 1.7 |
| NSF | 678 | 663 | 696 | 726 | 747 | 759 | 776 | 705 | -21 | -2.9 |
| USDA | 27 | 16 | 38 | 52 | 54 | 66 | 34 | 25 | -27 | -51.9 |
| Other federal | 604 | 647 | 620 | 678 | 604 | 588 | 631 | 597 | -81 | -11.9 |
| All nonfederally supported | 3,892 | 4,161 | 4,257 | 4,267 | 4,348 | 4,165 | 4,087 | 4,091 | -176 | -4.1 |
| Total, all sources of support | 5,420 | 5,753 | 5,900 | 6,002 | 6,054 | 5,905 | 5,856 | 5,713 | -289 | -4.8 |
| Electrical Engineering | | | | | | | | | | |
| All federally supported | 3,529 | 3,791 | 3,986 | 4,033 | 3,974 | 4,004 | 3,927 | 4,338 | 305 | 7.6 |
| DOD | 1,636 | 1,623 | 1,680 | 1,734 | 1,649 | 1,699 | 1,647 | 1,961 | 227 | 13.1 |
| DHHS, total | 77 | 85 | 90 | 103 | 100 | 113 | 93 | 113 | 10 | 9.7 |
| NIH | 55 | 76 | 81 | 86 | 83 | 84 | 71 | 68 | -18 | -20.9 |
| NSF | 1,131 | 1,253 | 1,360 | 1,260 | 1,266 | 1,298 | 1,298 | 1,324 | 64 | 5.1 |
| USDA | 16 | 18 | 24 | 9 | 24 | 33 | 12 | 14 | 5 | 55.6 |
| Other federal | 669 | 812 | 832 | 927 | 935 | 861 | 877 | 926 | -1 | -0.1 |
| All nonfederally supported | 14,428 | 15,408 | 16,246 | 15,636 | 14,745 | 13,565 | 13,462 | 13,963 | -1,673 | -10.7 |
| Total, all sources of support | 17,957 | 19,199 | 20,232 | 19,669 | 18,719 | 17,569 | 17,389 | 18,301 | -1,368 | -7.0 |

*continued*

**TABLE A-32** Continued

| Field and Source of Support | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | Change, 1993–1997 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Number | Percent |
| Mechanical Engineering | | | | | | | | | | |
| All federally supported | 2,494 | 2,697 | 2,753 | 2,952 | 2,885 | 2,726 | 2,546 | 2,559 | -393 | -13.3 |
| DOD | 735 | 724 | 715 | 777 | 763 | 801 | 709 | 725 | -52 | -6.7 |
| DHHS, total | 69 | 71 | 87 | 86 | 79 | 93 | 76 | 109 | 23 | 26.7 |
| NIH | 68 | 58 | 77 | 70 | 70 | 82 | 63 | 70 | 0 | 0.0 |
| NSF | 637 | 732 | 786 | 805 | 779 | 734 | 764 | 832 | 27 | 3.4 |
| USDA | 26 | 29 | 26 | 9 | 10 | 4 | 13 | 12 | 3 | 33.3 |
| Other federal | 1,027 | 1,141 | 1,139 | 1,275 | 1,254 | 1,094 | 984 | 881 | -394 | -30.9 |
| All nonfederally supported | 8,095 | 8,718 | 9,326 | 9,176 | 8,757 | 8,207 | 7,891 | 7,615 | -1,561 | -17.0 |
| Total, all sources of support | 10,589 | 11,415 | 12,079 | 12,128 | 11,642 | 10,933 | 10,437 | 10,174 | -1,954 | -16.1 |

Notes: (1) Ninety-three percent of all full-time graduate students, and 99 percent of federally supported full-time graduate students, were enrolled in doctorate-granting institutions in 1997; (2) Graduate students are reported according to the source of “the largest amount” of support received in fall 1997.
Source: NSF (1999, Table 38).

**TABLE A-33** Changes in Graduate Enrollment and Federal Funding of University Research, Selected Fields, FY 1993–1997 (full-time graduate students in doctorate-granting institutions and federal research in constant dollars)

| | Number of Graduate Students | | | Federal funding of research in Universities(%) |
|---|---|---|---|---|
| Field | All Sources of Funding (%) | Federally Funded (%) | Nonfederally Funded (%) | |
| All S&E fields | -5.1 | -6.0 | -4.9 | 2.8 |
| Computer sciences | 4.2 | 8.0 | 3.3 | 13.0 |
| Biological sciences | 0.9 | 0.4 | 1.2 | [a]14.3 |
| Chemical engineering | -4.8 | -6.5 | -4.1 | -12.7 |
| Electrical engineering | -7.0 | 7.6 | -10.7 | -31.9 |
| Mechanical engineering | -16.1 | -13.3 | -17.0 | -40.9 |

[a] Includes environmental biology because graduate students in environmental biology are included in biological sciences in the survey of graduate students and postdoctorates.
Notes: (1) Ninety-three percent of all full-time graduate students, and 99 percent of federally supported full-time graduate students, were enrolled at doctorate-granting institutions in 1997; (2) Graduate students are reported according to the source of "the largest amount" of support received in fall 1997; (3) Federal support of university research is reported only for six agencies: USDA, DOD, DOE, DHHS, NASA, and NSF.
SOURCES: (1) Graduate students: Table A-29; (2) federal funding: Table A-3 (constant dollars).

federal funding of university research declined by more than 40 percent (from Table A-7). Not surprisingly, then, the number of graduate students funded by federal agencies and by nonfederal sources was down, by 13 and 17 percent, respectively (Table A-32).

Electrical engineering is harder to interpret. Real federal support of academic research in electrical engineering declined by 32 percent between 1993 and 1997 (from Table A-5). Although the overall number of graduate students declined, as might be expected, the number of federally supported graduate students increased (Table A-32).

Federal support of computer science increased between 1993 and 1997 in real terms (the NSF survey reported an increase of nearly 13 percent, but it was probably less for reasons explained earlier) (Table A-27), and the number of federally funded graduate students in computer science also increased, by 8 percent (see Table A-33). The number of nonfederally funded graduate students also increased but by a smaller percentage (3 percent). Since they constituted the vast majority—more than 80 percent—of the graduate students in computer science, overall enrollment went up about 4 percent (Table A-32).

In the biological sciences, even though the level of federal support of university research was up substantially in 1997 compared with 1993 in real terms—more than 14 percent (including environmental biology)—the number of graduate students in biology hardly increased at all—by less than 1 percent. Federally supported graduate students increased even more slowly—by less than 0.5 percent.

The lack of consistent correlations between changes in federal research funding and changes in graduate enrollments is probably attributable to several factors. First, in most fields the federal government supports a fairly small proportion of graduate students. Second, there is bound to be a lag in the effect of federal research funding changes on graduate enrollments as current students work their way through graduate school and before the decisions of prospective students not to enter graduate school in a shrinking field can be felt. The data series is too short to ascertain whether there is a lagged effect. Third, although much federal support of graduate students comes thorough research grant funding in the form of research assistantships, some of it comes through specific fellowship and traineeship programs that are not counted as R&D. DHHS has the largest such programs, and NSF also has substantial fellowship and traineeship programs. If agencies protected education and training programs relative to research grant programs in budget downsizing, the number of federally funded graduate students could increase as research funding remained the same or declined.

## OBSERVATIONS

In many fields of science and engineering a single mission agency is the principal source (50 percent or more) of federal support for research. It is natural to assume that, if the research budgets of such agencies are shrinking, the fields they support will be similarly affected. This analysis shows that it is not necessarily true that an agency's level of funding for a particular field goes down or up with the fortunes of the agency's overall research budget. Agencies do not cut or increase programs across the board. They may, and often do, protect some fields from cuts, cut them less, or even let them grow despite a shrinking research budget. Of course, that implies even deeper funding cuts in other fields supported by the shrinking research budget. Conversely, an agency with an increasing budget may hold down or even cut the level of support for one or more fields and give larger increases to other fields. Thus, it is important to assess funding trends for agencies and fields together.

In the period 1993 to 1997 the fields disadvantaged by changes in agency budgets included most fields of engineering (apart from aeronautical and materials engineering), physics, mathematics, and chemistry. The field that benefited most by the changes during this period was medical science. Fields whose funding fortunes did not comport with those of their major sponsor were computer science and materials engineering, which grew despite DOD cuts.

Although university research increased slightly from 1993 to 1997, support by field was also variable. In the 15 research fields examined in this paper, federal spending increased in only six and was lower in nine fields. In many fields university research support fared better than overall research funding—that is, it decreased by a smaller percentage (chemical engineering, electrical engineering, mechanical engineering, physics, and geology) or increased by a larger percentage (metallurgy & materials engineering, biological sciences, atmospheric science and oceanography), but there were exceptions (chemistry, mathematics, and computer science). In two fields (medical sciences and aeronautical engineering), university research support declined while overall support increased.

Although there are instances in which a second agency has "picked up the slack" in a field receiving less support elsewhere, no single agency has explicitly or implicitly played that role, in contrast to the early 1970s when in response to cutbacks at NASA and DOD, NSF was charged by Congress to serve as the balance wheel of the system and the NSF budget was increased to pick up some of the researchers previously funded by NASA and DOD. In contrast, during the 1990s, NSF reduced or held flat its levels of support for several fields being cut by mission agencies, including chemical engineering, electrical engineering, mechanical engineering, physics, mathematics, and geology. NSF did increase its level of support for some fields being cut by DOD—materials engineering and computer sciences. The 1996 changes in how NSF classifies research by field make it difficult to interpret some of the chanes from 1993 to 1997, especially in mechanical and materials engineering. Overall, however, NSF funding appears to have followed (or led) aggregate trends, generally boosting funding for fields that prospered and reducing funding for fields that suffered reductions.

It should be acknowledged that, although NSF's research budget has increased faster than inflation, the percentage increases would not be nearly enough to compensate for the magnitude of cutbacks in some fields, given the relatively modest size of NSF's budget. NSF provides support for most fields of science and engineering but typically accounts for 10 to 15 percent or less of total federal research funding in an individual field.

The reverse of stepping up funding to compensate for a drop in another agency's support of an important field would be for an agency under budget pressure to cut back because of increases elsewhere in the federal government. This may have been a factor in DOD's reductions in the biological sciences and medical research.

It is probably too early to see the effects of changes in levels of federal funding of research, even large ones, on graduate enrollments, let alone degree attainment rates. Such effects, if they do appear, will probably be attenuated because federal funding is not the principal source of support for graduate students in most fields.

Finally, what about the argument that having diversified agency research support is preferable to being dependent on a single major source of support because it is less vulnerable to sudden budget changes? This analysis provides little support for that hypothesis. One field with a broad base of federal funding support came out of the downturn in research funding between 1993 and 1997 with a larger budget in real terms (oceanography, +16.4 percent), but as explained above, most or all of that increase may be more apparent than real, resulting from changes in NSF classification procedures. The rest had substantially smaller budgets (chemistry, -8.7 percent; chemical engineering, -12.9 percent; geology, -21.1 percent; mathematics, -5.6 percent; and civil engineering, -12.9 percent) (see Figures A-15 and A-16).

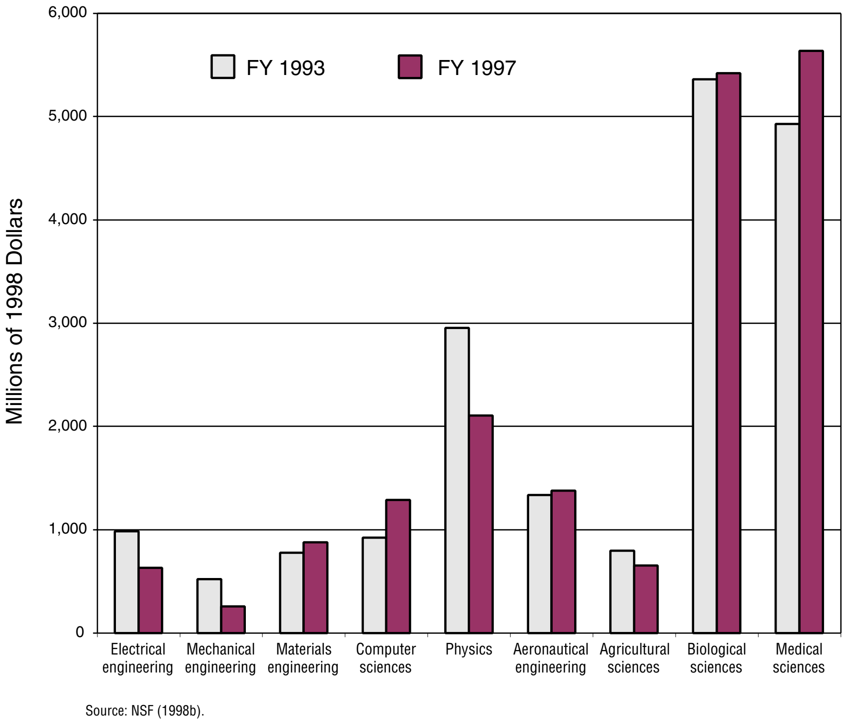
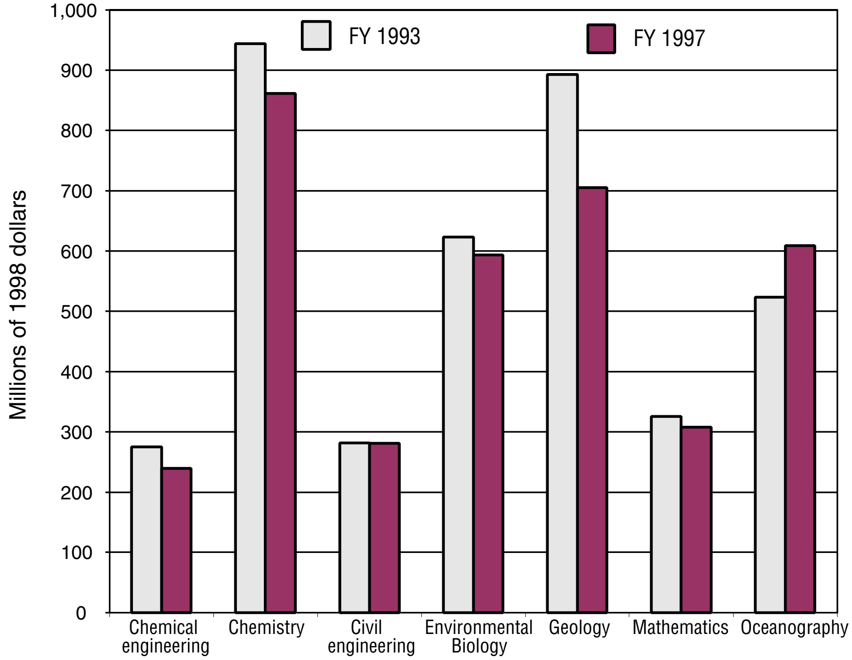



**FIGURE A-15** Federal research funding of fields with majority of support from one agency, FY 1993 and FY 1997.
Source: NSF (1998b).




Source: NSF (1998b).

**FIGURE A-16.** Federal research funding, of fields with support from multiple agencies, FY 1993 and FY 1997.
Source: NSF (1998b).

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# APPENDIX B

# Trends in Industrial Research and Development: Evidence from National Data Sources

Stephen A. Merrill and Ronald S. Cooper

## R&D AND INNOVATION DATA

From an economic standpoint, industrial research and innovation are important primarily as contributors to economic growth, productivity, and welfare. Innovation refers broadly to the invention, commercialization, and diffusion of new products, processes, and services. Research and development (R&D) are only two of the factors that influence innovation and that we seek to understand and monitor so that, presumably, policymakers will be in a better position to stimulate technology development and its application.

Ideally, the collection of national and international data[1] on innovation should be guided by a solid theoretical understanding of the process and its impacts. Such understanding of causes and effects, while being developed, is not very far advanced. It is possible, however, to elaborate a conceptual framework that encompasses direct indicators of innovation, influences on innovation, and its effects. Such a scheme is presented in Table B-1. The three broad categories of innovation information include (1) measures of innovative output—newly commercialized products, processes, or services and their characteristics; (2) factors that influence innovative activity such as the level of research effort, channels of

[1] By national data we mean data on nationwide trends in major sectors of the economy. Generally speaking these include national survey data (e.g., various R&D expenditure surveys, the Bureau of Labor Statistics survey of occupations), administrative data collected for other purposes (e.g., patent applications and issuances, initial public stock offerings, exports, and imports), and tabulations of media-reported events (e.g., mergers and acquisitions, corporate strategic alliances).

**TABLE B-1** Inventory of Innovation Metrics

| Category of Indicator | Some Indicators/Metrics |
|---|---|
| **I. Direct Measures of Innovation** (Used to show changes in the level, rate, direction, and composition of innovation—defined as *the invention and commercialization of new products, processes and services.*) | |
| • Invention/introduction of new products, processes, and services<br>— Level, rate, direction, and composition (by industry, technology area, character of innovation, funder, performer) of innovation | • Invention/innovation disclosures, new product announcements<br>• Innovation counts |
| | • Patent counts (by industry, technology area), weighted by forward citations<br>• New products, processes, services introduced<br>• Shares of sales attributable to new products and services (new sales ratio) |
| • Diffusion of new products, processes, and services | • Use over time and space of new products, processes, services, (by industry, technology area) |
| **II. Determinants of Innovation** | |
| **A. Industrial Innovative Effort** | |
| • R&D spending | |
| — Reported corporate R&D expenditures | • Reported company R&D expenditures (by industry, technology area, character of work) |
| — Informal R&D activities in other business units | • Survey questions on R&D performed and funded by non-R&D business units |
| • Non-R&D innovation-related spending | • Survey questions on innovation-related expenses: design, engineering, prototyping, production, and marketing |
| • Technical human resources | • Number of technical employees, by industry and technology area<br>• Survey of doctoral recipients (matched to company innovation indicators) |
| **B. Organization and Structure of Innovative Activity**: Technical knowledge generation and transfer | |
| • Organization within the firm | • Survey questions regarding: Relations of R&D to other business functions<br>• Survey questions: Central *vs.* business unit R&D |
| • Alliances, collaborative arrangements<br>— Interfirm alliances and collaboration | • Strategic technology alliance counts (international) |
| | • Licensing agreements<br>• Cooperative R&D ventures |

**TABLE B-1** Continued

| Category of Indicator | Some Indicators/Metrics |
|---|---|
| — Industry-university collaboration | • University patents<br>• University patent and licensing revenues |
| — Industry-government collaboration | • Cooperative research and development agreement (CRADA) counts and values |
| — Industry collaboration with private nonprofit research centers | • Contracts |
| • Regional clustering of innovative activities (proximity effects on innovation, key institutional linkages) | • Company survey questions: sources of information with location<br><br>• Patents linked to geographic location, e.g. location (metropolitan statistical areas, or MSAs)<br>• R&D expenditures linked to geographic location<br>• Patent citations |
| • Multinational location of research and innovative activity/capacity | • Foreign direct investment (R&D)<br><br>• Strategic technology alliance counts<br>• Technical employees<br>• Patents<br>• Patent citations |
| • Customer/user feedback | |
| • Informal knowledge flows | • Scientific and engineering publications (bibliometric data)<br>• Consultantships, meetings, informal trading, etc.<br>• Patent citations to previous patents and scientific literature |
| **C. Legal and Market Conditions** | |
| • Intellectual property protection used (patents, secrecy, first mover, etc.) | • Survey data on use of intellectual property mechanisms (by industry, technology area) |
| • Structure and competitiveness of markets, intensity and form of rivalry | • Survey data on competition<br>• Rate of innovation, by industry<br>• Industry concentration |
| • Rate of technological obsolescence | |
| • Market demand | • Sales trends linked to innovative activity<br>• Price elasticities |
| **D. Technological opportunity:** Vitality and relevance of the underlying scientific knowledge | |
| | • Benchmarking<br>• Field assessments |

*continued*

**TABLE B-1** Inventory of Innovation Metrics

| Category of Indicator | Some Indicators/Metrics |
|---|---|
| **III. Impact of Innovation** | |
| **A. Productivity** | • Productivity estimates by industry |
| **B. Employment**—job creation and destruction, skill biases, wage levels | • Employment and job creation data linked with skill and wage levels |
| **C. Firm and industry performance** (profits, competitiveness) | • Profits over time, by industry,<br>• Market share over time<br>• New product sales ratio |
| **D. Economic growth** (national, regional development) | • Aggregate and regional economic indicators linked to aggregate and regional innovation indicators |
| **E. Social welfare effects, human capital development** (e.g., effects of information technologies access and use) | |

knowledge flows, the means of appropriating innovation results, relevant industry structure and market conditions, and technological opportunities; and (3) the impact of innovation on firms, regions, workers, and the economy as a whole.

As it happens, there are important variables on which no data are currently collected on a national basis and regular schedule for major sectors of the economy. These gaps include but are not limited to direct measures of innovation (e.g., newly commercialized products, processes, and services); extent of use of new processes, products, and services (i.e., diffusion); and investments other than R&D necessary for successful innovation (e.g., innovation-related spending on design, engineering, production, and marketing). Apart from scientific and engineering publications, data are lacking on the many informal channels of transferring know-how within the firm, between customers and sellers, and across competing firms. Similarly, we have few reliable data on the career mobility and structure of work of industrial scientists and engineers, as distinct from their formal educational qualifications and employment status; and we lack measures of the technological opportunities underlying important innovations.

In contrast, R&D expenditure statistics are available from several sources. The principal sources are the National Science Foundation's annual survey of corporate R&D carried out by the Bureau of the Census; publicly held companies' 10K form filings with the Securities and Exchange Commission (SEC) and made available by Compustat; data collected over the past six years by the Center for Innovation Management Studies (CIMS) of Lehigh University from firms affiliated with the Industrial Research Institute (IRI); and other private surveys (e.g., McGraw-Hill, Battelle Memorial Institute). There are notable differences in coverage and in disaggregation among these datasets. The principal differences include the following:

- *Universe of firms surveyed:*
  - — The National Science Foundation's (NSF) RD-1 survey includes private as well as publicly held companies, for activities carried out in the United States only. Reporting of R&D funds spent in foreign locations is voluntary.
  - — Compustat's 10-K form data cover only publicly held U.S. companies but include their foreign operations. Excluded are U.S.-based operations of foreign firms.
  - — The IRI/CIMS survey collects R&D expenditure data from IRI member companies, which account for about 75 percent of U.S. industrial R&D but underrepresents small firms. Moreover, the response rate, especially to detailed questions, is quite low; only 30 companies responded to the survey in all of the past five years.

- *Level of aggregation:*
  - — NSF's RD-1 survey reports expenditures only at the firm level, and firms are requested to allocate their R&D across two- or three-digit level Standard Industry Classification (SIC) categories which are relatively nonhomogeneous.
  - — Compustat data are primarily at the firm level but contain some business segment detail.
  - — The IRI/CIMS survey collects data at the company and business segment levels. R&D expenditures are categorized at the four-digit SIC level, but the survey's response rate is generally too low to be considered representative of any sector of the economy.

- *Character of innovative activity:*
  - — NSF surveys of both public and private R&D expenditures classify activities as basic research, applied research, and development, which are defined in standard ways. NSF's RD-1 survey no longer asks for a short-term/long-term breakdown of expenditures or the fields of industry-funded basic research.
  - — Companies are not required to report information on the character of R&D work to the SEC.
  - — The CIMS R&D survey breaks expenditures down by basic/applied/development and uses a fourth category, "technical services."

In addition, administrative data exist on industrial R&D collaborations among companies and between companies and federal laboratories. The former consist of registrations of agreements with the Department of Justice under the National

Cooperative Research and Production Act. The latter are counts of so-called cooperative research and development agreements, or CRADAs. Tabulations of certain media-reported events such as the formation of strategic alliances between international firms are maintained on a regular basis.

The relative abundance, industry and firm detail, consistent collection, and broad industry coverage of R&D data drive much of the analysis of industrial innovation, although in the conceptual scheme described above they are not a direct measure of innovation. Here the objective is simply to assess more systematically what is known about recent trends in R&D, particularly the research component, from national data collected and reported by the federal government and other organizations.[2] In addition to partially illuminating some trends, this exercise reveals significant limitations and gaps even in R&D information. How to overcome these limitations that hamper our understanding of R&D trends was one of the subjects of a Board on Science, Technology, and Economic Policy (STEP) on industrial research and innovation indicators for public policy (Cooper and Merrill, 1997).[3]

## INNOVATION TRENDS

It is evident from the above inventory that the pattern, determinants, and effects of innovation involve variables that change over time, sometimes remarkably quickly and radically. At no time has that been more apparent than in recent years. There has been a great deal of discussion about changes in innovation processes. Several general trends are often presumed to be rapid, substantial in magnitude, and consequential to economic performance, both positively and negatively. These changes include (1) shifts in the industry and technology distribution of innovative activity, (2) shifts in the time horizon of innovative effort and investment or the orientation of innovation, (3) changes in the organizational structure of innovative activity, and (4) changes in issues concerning the location of innovative activity both within the United States and globally.

The hypothesized changes and the concerns associated with them are as follows:

[2] As a result of substantial changes in the NSF RD-1 survey investment at the beginning of the 1990s to increase representation of service-sector firms and small businesses, there is a discontinuity in the RD-1 survey data that makes post-1991 trends not strictly comparable with previous years' patterns. Nevertheless, 1988–1991 statistics were revised after being first reported, to reduce the discrepancy.

[3] The suggestions of workshop participants for improving R&D included collecting information at the business-unit level of corporate activity rather than for the firm as a whole, adjusting the firm sample to incorporate emerging, high-growth, technology-intensive firms in the service as well as manufacturing sectors, collecting geographic location detail, and taking steps to link R&D with other economic data such as census establishment data.

- *Industry distribution:*
  — The sectoral and technological distribution of U.S. industrial research and innovation is shifting toward nonmanufacturing and new emerging industries and technologies. This is of concern to the extent that some industries are becoming less innovative.

- *Orientation:*
  — U.S. firms have been conducting less fundamental research with longer-term payoffs, focusing instead on more incremental innovative efforts with clear market applications and generally shorter time horizons. If this is widespread and continues, it may lead to a weakening of U.S.-located innovative capacity in the long term. In the near term it may have enhanced firms' performance.

- *Organization:*
  — In-house R&D activities have been decentralized as firms have shifted away from the central R&D lab model. Decentralization of intrafirm innovative activity may have resulted in greater integration of R&D with corporate strategy and with other business units (product design, marketing, etc.), but unique technical resources of central corporate laboratories may have been lost in the process.
  — Collaboration in and outsourcing of research and innovation are increasing, both among firms and between firms and universities and government laboratories (contracting, research joint ventures, licensing agreements, strategic alliances). This may improve the efficiency of innovative activities by reducing redundancies and accelerating implementation and diffusion. On the other hand, it may also involve a "hollowing-out" of companies' innovative capacity, with possible negative effects on long-term corporate competitiveness. The role of universities as the principal performer of basic research appears to be changing as university-industry collaboration increases. This may facilitate the application of academic research results but may also undermine the autonomy and distort the mission of universities.

- *Location:*
  — As firms continue to outsource many of their innovation-related activities and work closely with universities and other public and private research centers, successful innovation appears to depend increasingly on geographically clustered networks of related organizations. Substate regions such as Silicon Valley, Research Triangle Park, and Austin, Texas, prosper while other regions without the key infrastructure may experience economic decline.
  — Firms in some industries have shifted R&D capacity abroad and entered

into alliances with foreign firms, possibly gaining access to human talent, technology, and markets but also reducing the likelihood of U.S. location for industry growth. At the same time, foreign firms have invested more in U.S.-based R&D activities.

### Overall R&D Effort

Private-sector R&D spending was relatively static in the first half of the 1990s, but then, in contrast to the pattern in federal R&D, spending accelerated at a rate of 9 percent in 1995 and 1996 and is estimated to have increased 4 percent in 1997 and 7.7 percent in 1998 (see Table B-2).

### Industry Distribution of R&D

The most striking recent change in industrial R&D effort, in part a function of the change in the National Science Foundation's survey sample, is the sharp increase in the service sector's share of total industry-funded R&D, from 8.4 percent in 1987 to approximately one-quarter in 1995. In all probability, firm-level rather than business segment reporting in the NSF survey and the SEC filings results in an underestimate of the amount of services, particularly information technology-related R&D, inasmuch as the service functions in many major industrial corporations have expanded. At the same time, this expansion has

**TABLE B-2** Corporate-Funded R&D Performance by Industry (millions of current dollars)

| | Total Corporate R&D Funding | Basic Research | Percent | Applied Research | Percent | Ratio of R to D |
|---|---|---|---|---|---|---|
| 1985 | 57,043 | 2,373 | 4.2 | 12,908 | 22.6 | 26.8 |
| 1986 | 59,932 | 3,496 | 5.8 | 15,082 | 25.2 | 31.0 |
| 1987 | 61,403 | 3,583 | 5.8 | 15,153 | 24.7 | 30.5 |
| 1988 | 66,672 | 3,507 | 5.3 | 16,531 | 24.8 | 30.1 |
| 1989 | 73,501 | 3,832 | 5.2 | 17,993 | 24.5 | 29.7 |
| 1990 | 81,602 | 3,760 | 4.6 | 18,432 | 22.6 | 27.2 |
| 1991 | 90,580 | 6,125 | 6.7 | 21,425 | 23.6 | 30.3 |
| 1992 | 94,388 | 5,816 | 6.2 | 21,184 | 22.4 | 28.6 |
| 1993 | 94,591 | 5,961 | 6.3 | 19,956 | 21.1 | 27.4 |
| 1994 | 97,131 | 6,078 | 6.3 | 19,372 | 19.9 | 26.2 |
| 1995 | 108,652 | 5,379 | 5.0 | 23,755 | 21.9 | 26.9 |
| 1996 | 121,015 | 6,848 | 5.6 | 25,370 | 20.9 | 26.5 |
| 1997 | 133,611 | 8,766 | 6.5 | 29,782 | 22.3 | 28.8 |

Source: National Science Foundation (1999, Table A27).

shifted some firms from the "manufacturing" to the "service" category where their continuing R&D related to tangible products and manufacturing processes is now counted. The reclassification of some major companies accounts in significant part for the sharp decline in expenditures and R&D intensity in office and computing machinery. This underscores that the distinction is increasingly artificial, especially but not exclusively at the firm level.

Within the "manufacturing" sector, in constant dollars and as a share of sales, since the late 1980s R&D has increased in most broad industrial sectors, including electrical components, telecommunications, drugs, and even metals and apparel and textiles. The most surprising increase in R&D spending has been in motor vehicles. On the other hand, expenditures and R&D intensity have declined sharply in chemicals (see Figures B-1 and B-2).

These relatively highly aggregated categories (primarily two-digit and in a few cases three-digit-level SIC) may obscure changes that would be apparent at a finer (e.g., four-digit SIC) level of detail, where the categories are more homogeneous. Two-digit categories especially contain heterogeneous products of very different levels of technological sophistication and R&D content. For example, "office computing and accounting equipment" includes calculating and adding machines as well as computers. "Professional and scientific instruments" encompasses photographic equipment as well as analytical and laboratory apparatus, and "electronic components" includes tubes as well as semiconductors. Finally, "other chemicals" includes soaps, detergents, and ink as well as fertilizers.

Changes in corporate rankings in R&D expenditure, on the other hand, show a much more focused trend—the growth of information technologies and pharmaceuticals, almost to the exclusion of other sectors. For example, among the top 50 U.S.-based companies in R&D spending in 1996, all of the companies advancing 10 places or more in the previous 10 years were in these two sectors (see Table B-3).

## Orientation of R&D

The hypothesis of shortening corporate investment time horizons and greater risk aversion suggests that firms are spending less of their resources on long-range exploratory research and more on incremental improvements in existing products and processes. It is not clear that this corresponds to the categories of R&D activity in which data are routinely collected—primarily, basic research, applied research, and development—but this is the only classification of the character of R&D across industrial sectors.[4]

On the basis of what is known about the increase in international competition and cost pressure on firms, it would seem reasonable to assume that investment in basic research—the acquisition of general knowledge and exploration of funda-

[4] See Appendix A for definitions.

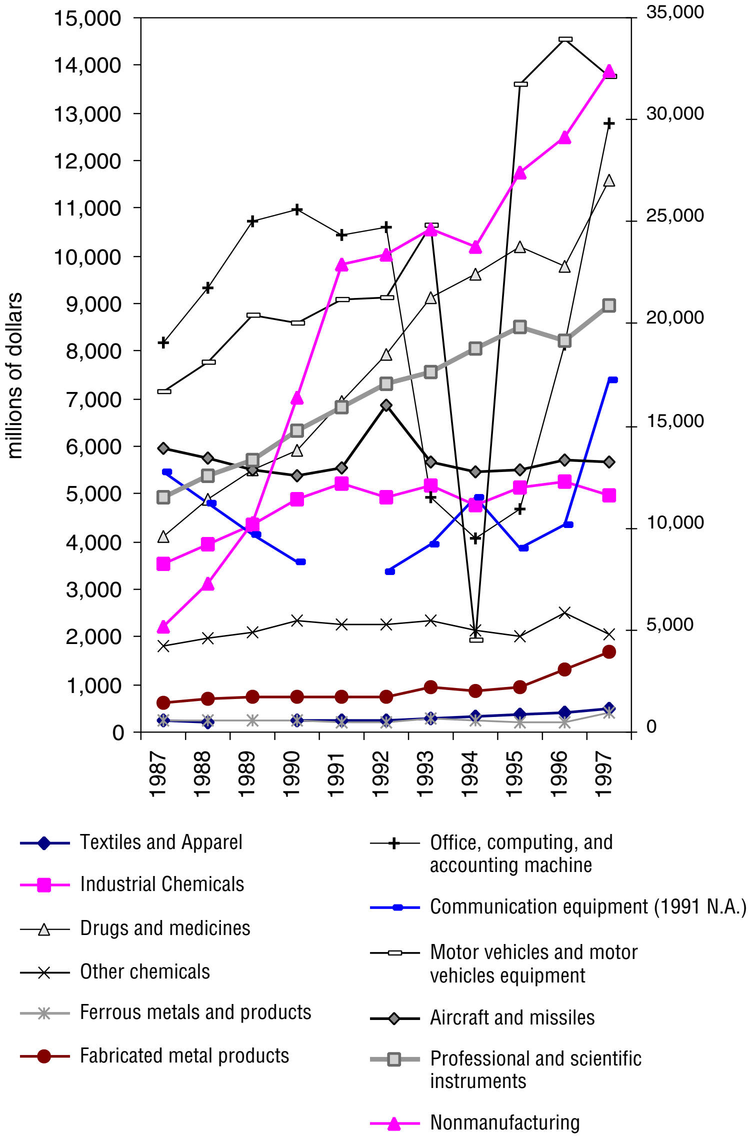


**FIGURE B-1** Company and other (except federal) funds for industrial R&D performance, by industry: 1987–1997 (millions of dollars).
Note: Detailed data by specific service industries are available only after 1994. Industries shown are the subject of industry performance case studies commissioned by STEP and published in Mowery, ed., 1999. Right hand scale refers to nonmanufacturing only; left hand scale applies to all other industries.
Source: National Science Foundation (1999, Table A-7).

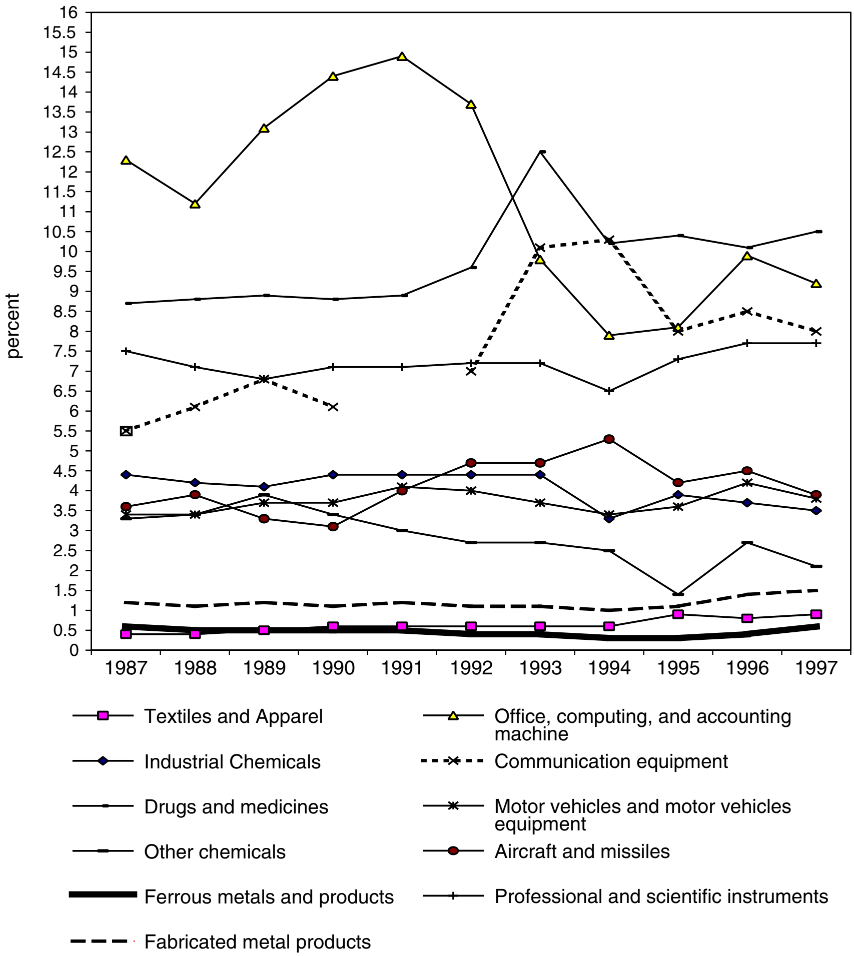


**FIGURE B-2** Company and other (except federal) industrial R&D funds as a percent of net sales in R&D-performing companies, by industry: 1987–1997.
Note: Industries shown are the subject of industry performance case studies commissioned by STEP and published in Mowery, ed., 1999.
Source: National Science Foundation (1999, Table A-22).

**TABLE B-3** Corporate R&D Expenditure Rankings (firms advancing ten places from 1986 to 1996)

| Information Technology Firms | Pharmaceutical Firms |
|---|---|
| Motorola (20/5) | Johnson & Johnson (18/8) |
| Intel (46/9) | Pfizer (31/10) |
| Microsoft (—/13) | Merck(22/12) |
| Sun Microsystems (—/35) | American Home Products (47/14) |
| Apple Computer (75/37) | Bristol Meyer Squibb |
| Seagate Technology (—/42) | Pharmacia & Upjohn (33/17) |
| Applied Materials (—/44) | Abbott Laboratories (38/19) |
| Compaq Computer (—/48) | Rhone Poulenc (—/29) |
| Advanced Micro Devices (60/49) | Schering Plough (53/33) |
| Cisco Systems (—/50) | Warner Lambert (58/38) |
| | Amgen (—/40) |
| | Genentech (—/46) |

Note: Numbers in parentheses are 1986 rankings (if in the top 100 companies) and 1996 rankings.
Source: National Science Board (1998, Table A-23).

mental concepts—has declined because of the difficulty of appropriating private returns and that investment in research generally—both basic and applied—has fared poorly relative to development expenditures. In fact, industrially funded basic research did decline in 1990 and again in 1995, both absolutely and as a share of corporate R&D, but the ratios partly reflected increases in total spending in 1995. In both cases, basic research subsequently recovered (Table B-2). The distinction between "basic" and "applied" research is sufficiently ambiguous and industry basic research is so modest, relatively speaking, that a better indicator of changing priorities, if any, is probably the ratio of total "R" to "R&D." This, too, dropped after 1991, although primarily as a result of reductions in applied rather than basic research. But the downward movement in research was quickly reversed in 1995 and subsequent years. In general, over the 1990s, the R share of industrial R&D is only slightly lower than it was at the end of the 1980s (see Figure B-3).

## Organization and Character of R&D

The CIMS survey data suggest that there has been a shift in the locus of R&D activity—both funding and performance—to business units away from central organizations, perhaps reflecting shorter time horizons but yielding a closer coupling of R&D to product development. The percentage of R&D labs engaged in basic research declined from 1988 to 1996, and business segment labs do relatively less basic research than do corporate labs (Beau et al., 1998 and 1999).

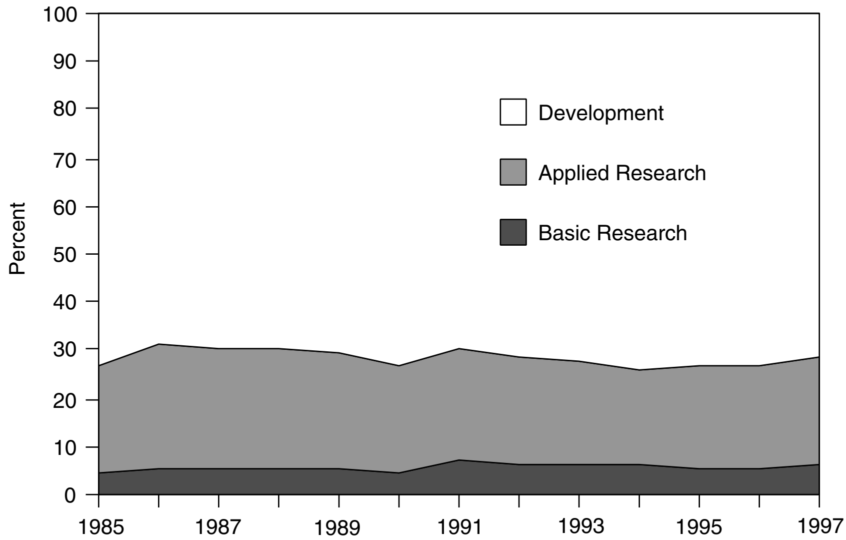


**FIGURE B-3** Orientation of industry-funded R&D.
Source: National Science Foundation (1999, Table A-27).

As these observations suggest, the CIMS data have the potential to yield much more detailed information about R&D trends. Firms are asked to report R&D expenditures not only for business segments (at the four-digit SIC level) but also for individual laboratories and to identify whether the source of funds is a business segment or corporate headquarters. Product and process R&D are distinguished as are "technical services" relating to but not identical with R&D. Finally, spending data are linked to measures of innovative output, patent applications, patents, and share of unit sales attributable to new or improved products. Despite this detail, the severe limitation of the CIMS survey is the low response rate overall, especially to the more detailed questions about innovative outputs. For example, 81 firms accounting for 20 percent of U.S. industrial R&D reported usable data in 1997, but only 30 firms have consistently reported usable data over the five years of the survey.[5]

In addition to decentraliztion of R&D within firms, there appears to be a pattern across industry sectors of firms expanding their use of external sources of research and technology through a variety of collaborative arrangements with other firms, universities, and government labs. Because the spillovers entailed in

[5] Results of the most recent survey and information on response rates are reported in Bean et al. (1999).

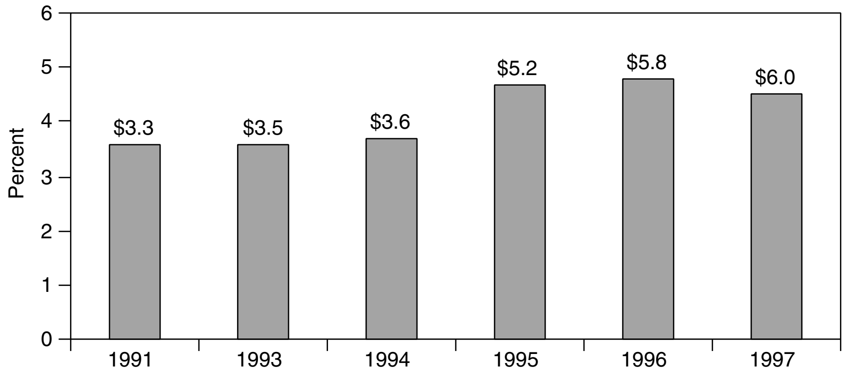


**FIGURE B-4** Company R&D contracted out (as a share of total company-financed R&D).
Note: Figures above bars represent billions of dollars.
Source: National Science Foundation (1999).

external collaborations are thought to increase efficiencies and expand opportunities, they have been actively encouraged by governments at all levels.

The incidence of outsourcing and external collaborations and acquisitions via contracting, grants, joint ventures, mergers, strategic alliances, and other mechanisms almost certainly increased significantly in the 1980s and 1990s; but available data do not confirm that external sources of research and technology have become more important to firms relative to internal sources and the myriad channels of informal communications.

NSF data from the RD-1 survey show that companies spent $6 billion in 1997 for R&D conducted outside their firms, via contracts and other arrangements with independent companies, universities, and not-for-profit organizations, but this represented only 4.5 percent of corporate R&D, an increase of less than one percentage point in six years (see Figure B-4).

Industry support of university research, while growing and of increasing importance to the recipient institutions relative to other sources,[6] still represents less than 1 percent of total corporate R&D, and that small share remained steady throughout the 1990s (see Table B-4).

Data on the number of strategic technology alliances, research and development joint ventures, and industry-government laboratory cooperative R&D agreements (CRADAs) concluded show in all cases marked increases through 1994 or 1995 (see Table B-5 and Figures B-5 and B-6), but a fall-off in growth in the last year or two for which data are available. In any case, for the most part these counts of discrete transactions fail to indicate their value in monetary or other

[6] Since the mid-1970s, industry's share of academic R&D funding has roughly doubled to about 7 percent.

**TABLE B-4** Corporate Support of University R&D

| | Corporate Funds to University R&D (millions of constant 1992 dollars) | Percent of Total Corporate R&D Going to Universities |
|---|---|---|
| 1991 | 770 | 0.81 |
| 1992 | 805 | 0.83 |
| 1993 | 822 | 0.87 |
| 1994 | 836 | 0.88 |
| 1995 | 858 | 0.83 |
| 1996 (preliminary) | 895 | 0.81 |
| 1997 (preliminary) | 926 | 0.78 |

Source: National Science Board (1998).

**TABLE B-5** Number of New CRADAs Executed, by Agency

| Agency | Total | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|
| Total | 3,512 | 502 | 877 | 1,130 | 1,003 |
| Agriculture | 270 | 41 | 103 | 72 | 54 |
| Commerce | 412 | 86 | 147 | 97 | 82 |
| Defense | 1,001 | 131 | 201 | 298 | 371 |
| Energy | 1,553 | 160 | 367 | 564 | 462 |
| Environmental Protection | 43 | 20 | 5 | 10 | 8 |
| Health & Human Services | 136 | 53 | 25 | 36 | 22 |
| Interior | 61 | 3 | 15 | 39 | 4 |
| Transportation | 36 | 8 | 14 | 14 | 0 |

Source: Technology Publishing Group (1997).

terms, their duration, and their importance relative to the myriad channels of informal knowledge exchange. Moreover, for purely private transactions, we can only speculate on the motivations for voluntary reporting, either to the press (strategic technology alliances) or to the government (research and production joint ventures) and whether reported arrangements are truly representative of their universes.

## Location of R&D Activity

Industrial innovation has become increasingly multinational through increased direct foreign investment in R&D facilities, development of digital communications, and expanded use of formal international cooperative agreements, joint research ventures, and other forms of strategic technology partnering. The growing multinational organization of innovative activity apparently affords

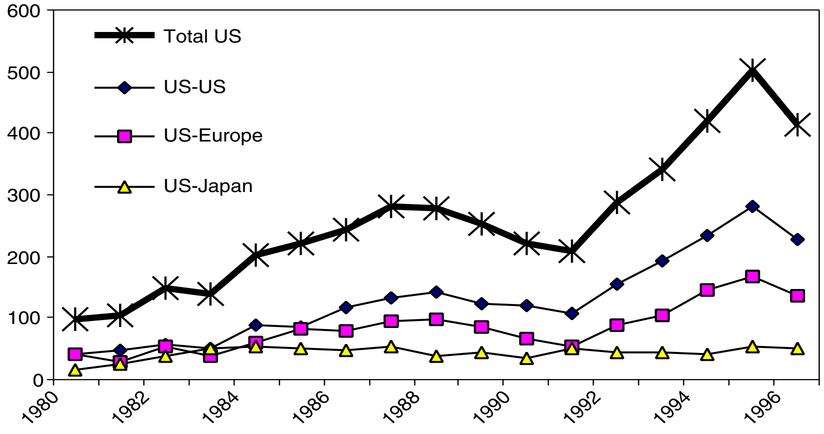


**FIGURE B-5** Strategic technology alliances with U.S. firms
Source: Maastricht Economics Research Institute on Innovation and Technology (MERIT)/ Cooperative Agreements and Technology Indicators (CATI) database. NSB-98, A4-48.

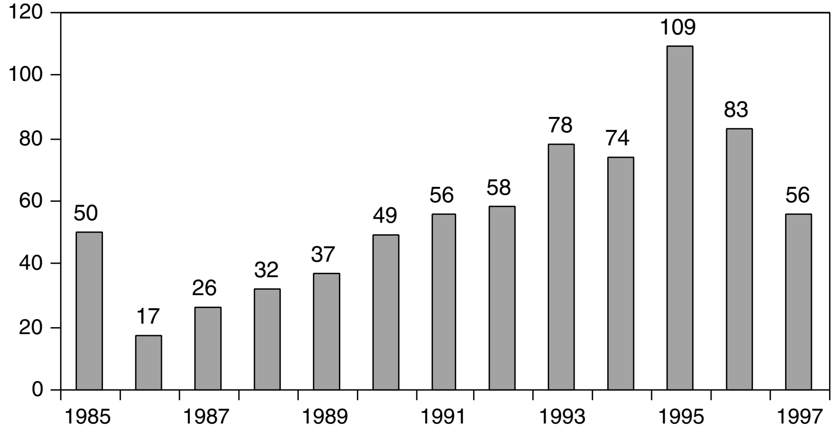


**FIGURE B-6** Research and production joint ventures: annual number of new filings under the National Cooperative Research Act (NCRA) and National Cooperative Research and Production Act (NCRPA).
Source: Unpublished data from the Department of Justice, Antitrust Division, Premerger Unit.

greater access not only to markets and materials but also to a broader array of technologies and skilled human capital, improving innovative efficiency. Public policy concerns center on the possible loss of domestic economic activity arising from an outward flow of knowledge and technology. Available national statistics shed little light on this issue.

The Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce tracks the inward and outward R&D investment flows for U.S. companies and affiliates of foreign companies. BEA data show that U.S. company R&D investment abroad has remained roughly in balance with R&D expenditures in the United States by majority-owned U.S. affiliates of foreign companies. There has been a slight shift in the aggregate balance from a net outflow in the late 1980s to a net inflow in 1993 and 1994 (see Figure B-7). The industry sectors with the greatest growth of foreign-based R&D activity by U.S. companies and their affiliates were chemicals (especially pharmaceuticals), scientific instruments, food, and nonmanufacturing such as computer software, data processing, and architectural services. As a share of total domestic corporate R&D, however, outward investment did not increase in the 1990s, remaining about 11 percent. Only inward investment increased from about 9 percent in 1989 to 14 percent in 1995.

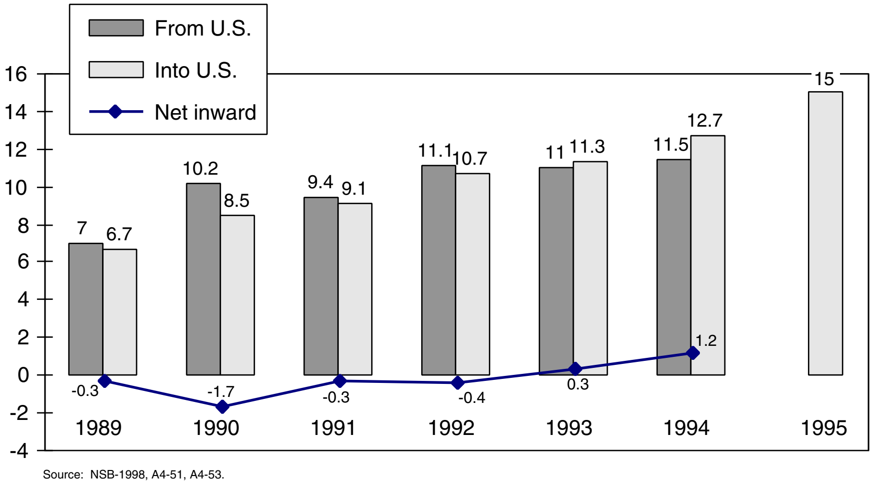


FIGURE B-7 U.S. and foreign industrial R&D investment (billions of dollars). Source: National Science Board (1998, A4-51, A4-53).

## SUMMARY

National data sources do not provide robust evidence of changes in U.S. industrial R&D that are widely thought to be substantial, continuing, and in some respects problematic from the standpoint of the national economic interest. This undoubtedly is a commentary about the limitations of the indicators, the less than satisfactory categories in which data are classified, and the high level of aggregation of the data more than it is evidence of the existence and magnitude of the trends. In light of these deficiencies, it cannot be inferred from the data that the changes are not real or that other trends equally consequential to economic performance are not occurring. On the other hand, the evidence does lead to questions about anecdotal data cited as evidence of the trends. What is certain is that without a concerted effort to improve R&D and other innovation indicators, we will continue to be in a relatively poor position to assess industrial innovation trends.

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