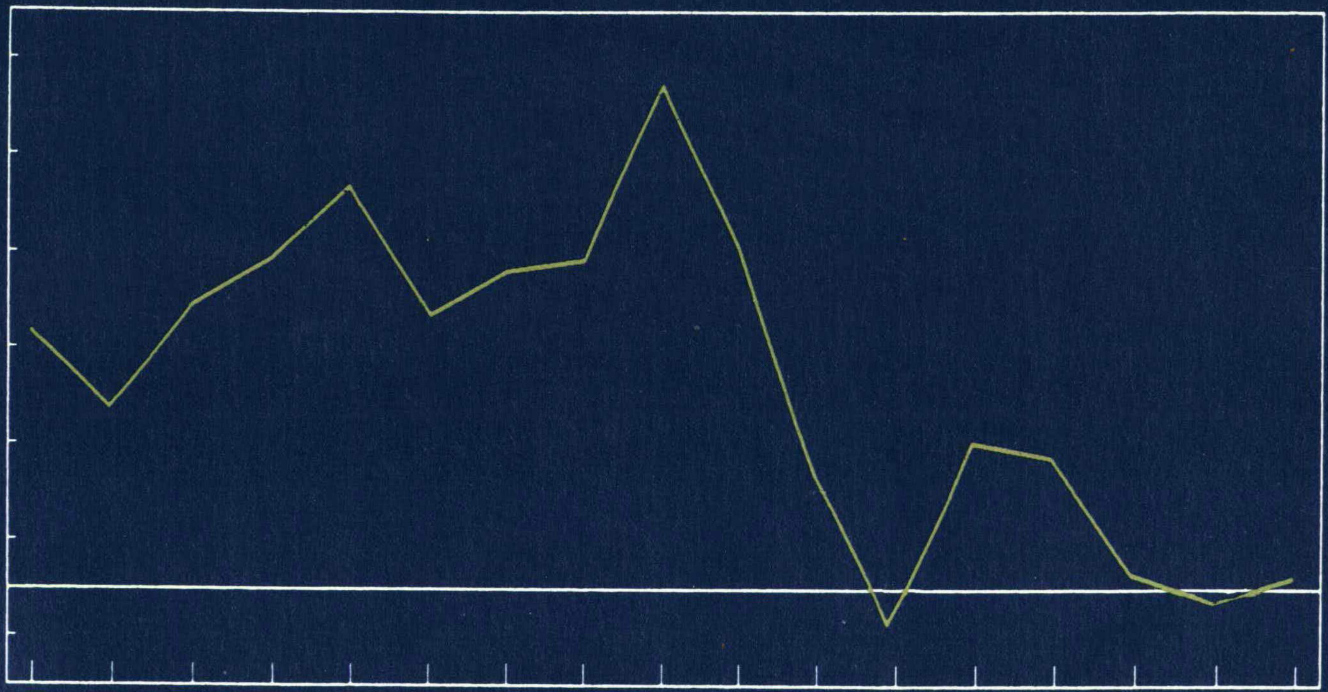
THE COMPETITIVE STRENGTH OF U.S. INDUSTRIAL SCIENCE AND TECHNOLOGY: STRATEGIC ISSUES



A REPORT OF THE
NATIONAL SCIENCE BOARD
COMMITTEE ON INDUSTRIAL SUPPORT FOR R&D

National Science Board

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Dr. Alden S. Bean, Director, Center for Innovation Management Studies, Lehigh University

Dr. Kenneth S. Flamm, Senior Fellow, the Brookings Institution

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Executive Summary

Many observers have commented that the competitive strength of U.S. industrial science and technology is declining. U.S. industry has already lost its leadership in several technologies critical to industrial performance, and it is weak or losing competitive strength in others. During the mid-1980s, U.S. investment in R&D increased at a sluggish pace, and the Nation's nondefense R&D expenditures did not increase as rapidly as those of many major foreign competitors. The Nation has also experienced relatively slow-paced product development and commercialization, since the results of U.S. R&D are not brought to market as effectively as those of foreign competitors. Compared to other countries, a high fraction of U.S. Government expenditures go to defense, rather than commercial, R&D.

These issues are of significance to the Federal Government, and specifically affect the National Science Foundation (NSF). Fundamental research supported by NSF in both science and engineering makes an important contribution to the competitive strength of U.S. industry.

The National Science Board (NSB), concerned about these issues, established the NSB Committee on Industrial Support for R&D to carry out a study on the nature of the problems and suggest broad remedies. The Committee felt that in addition to making general recommendations, it was important to make specific recommendations—some directed at NSF and other Federal agencies, others directed at the government in general.

This report represents the culmination of the Committee's effort to present an integrated, multidimensional view of the issues surrounding U.S. industrial R&D. This report is not intended to be a comprehensive study of U.S. international competitiveness. It focuses primarily on science and technology, particularly on the impact of R&D on U.S. competitive strength. The Committee recognizes that improving the U.S. R&D system—and, consequently, the U.S. scientific and technological position—will not in itself remedy all the ills of the U.S. economy or U.S. industrial competitiveness.

The Committee looked at R&D inputs (expenditures), intensity, content, and system outputs and compared them to those of foreign competitors. It invited several prominent authorities to express their views of industrial R&D in various industry groups. The Committee also used other recent, relevant studies and reports that have addressed these issues and the results of a survey conducted by the Industrial Research Institute (IRI) in cooperation with the Committee. The resulting composite picture throws new light on the major issues and on what should be done about them. The problems facing U.S. industrial science and technology are complex: there is no single problem, no simple solution. Policies and programs must address several dimensions simultaneously.

From its research, the Committee reached the following conclusions.

- The U.S. industrial R&D system is in trouble not only because the recent growth of R&D expenditures is lagging that of foreign competitors, but also because—in the view of many knowledgeable observers—the distribution and allocation of those expenditures is not optimal.

- Both Federal and corporate policies need to be improved if the Nation is to meet international competitive challenges.

- There are significant gaps in U.S. industrial R&D strength (e.g., in engineering research); further, a new threat is emerging to the country's traditional sources of strength—pioneering discoveries and inventions.

In short, the United States is spending too little, not allocating it well, and not utilizing it effectively.

Findings

The Committee's principal findings follow.

1. ***The real rate of growth in U.S. industrial R&D spending has declined since the late 1970s and early 1980s. In addition, the Nation's position has deteriorated relative to that of its major international competitors whose investment in nondefense R&D has been growing at a faster pace than U.S. nondefense R&D since the mid-1980s.***

   - Domestic industrial R&D expenditures slowed from an average annual growth rate of 7.5 percent (constant dollars) during 1980-85 to only 0.4 percent during 1985-91. The federally supported portion of these expenditures dropped from a growth rate of 8.1 percent to -1.7 percent over these two periods; industry's own support dropped from 7.3 percent to 1.3 percent. Almost all major R&D-performing industries contributed to this reduced growth rate.

   - Since 1985, U.S. growth in both total and nondefense R&D expenditures has been less than that of many of its major industrial competitors.

   - The United States now trails Japan and (West) Germany, its strongest competitors, in nondefense R&D spending as a percentage of gross domestic product (GDP).

2. ***The allocation of U.S. R&D expenditures is not optimal.***

   - The balance between defense and nondefense expenditures is disadvantageous compared to that of foreign competitors.

   International data for defense and nondefense components of total R&D expenditures (not industrial alone) as a percentage of GDP can be compared. Using six countries—Japan, (West) Germany, France, the United Kingdom, Italy, and Sweden—as a benchmark, the United States in 1989 spent almost as much as they did on total R&D, but 25 percent less on nondefense R&D.

   This imbalance has been deteriorating: the fraction of U.S. expenditures on nondefense R&D decreased slightly (from 74 to 71 percent) during the 1980s, while that of the competitor group increased (from 90 to 92 percent). Thus, during the 1980s, these six competitors moved from being 22 percent ahead of the United States in nondefense R&D expenditures to being 34 percent ahead. This increase has been driven largely by Japan's huge growth in nondefense R&D spending; today, Japan spends about 3 percent of its GDP on nondefense R&D, compared to 1.9 percent for the United States.

- Too little is spent on process-oriented R&D.

  Several studies have found that U.S. industrial R&D is weighted much more heavily toward product technology rather than process technology. U.S. firms also allocate a disproportionately small share of their R&D budgets to the search for new and/or improved processes compared to their Japanese counterparts.

- Inadequate effort is devoted to fundamental engineering research.

  The rapid conversion of ideas into products and processes requires command of an ever-expanding engineering knowledge base. Yet there is an insufficiently broad and deep fundamental engineering research base on which to build.

- There is insufficient emphasis on emerging and precompetitive technologies.

  In the IRI survey, industry's "reluctance to invest in new enabling technologies because the R&D may be too expensive, long-term, multi-industry, and interdisciplinary" received the largest number of first place rankings as a factor adversely affecting U.S. industry's ability to compete in global markets for high-technology products under the major category of *technology management practices*.

- The United States faces an emerging risk of losing its traditional strength in pioneering discoveries and inventions.

  Most pioneering advances of the past that have created the basis for new industries have originated in either the corporate laboratories of private firms or in research universities. Both of these institutions are under severe stress today.

3. ***U.S. expenditures are not as effective as they should be in producing needed results.***

- The U.S. competitive position in important, technologically based industries is deteriorating.

  The once strong across-the-board U.S. position of a decade ago has deteriorated substantially. U.S. industry has already lost its leadership in several technologies that are critical to industrial performance, and is weak or losing competitive strength in others.

- The U.S. time horizon has become too short, and the Nation's business decisions tend not to be based on strategic technological considerations.

  In large corporations, effort is shifting away from central laboratories toward division-level effort with greater emphasis on risk minimization to meet the needs of today's customers; emphasis is also shifting away from new markets toward existing markets.

- U.S. R&D is not translated into beneficial economic and social results quickly enough.

  Many companies trail their foreign rivals in the commercialization of new technology. In many U.S. industries, development of new products proceeds at a much slower pace than in other countries.

4. ***The current information base on industrial science and technology is inadequate: it has gaps, is questionable in parts, and does not provide enough detail to meet the needs of policymakers.***

Recommendations

The Committee's findings lead to significant apprehension about the present trajectory of U.S. industrial R&D and to the conclusion that stronger Federal leadership is needed in setting the course for U.S. technological competitiveness. Implementation of a national technology policy, including establishment of a rationale and guidelines for Federal action, should receive the highest priority. The start of such a policy was set forth 2 years ago by the President's Office of Science and Technology Policy, but more forceful action is needed by the President and Congress before there is further erosion in the U.S. technological position.

The Committee's recommendations focus on areas where NSF or other agencies of the Federal Government may be able to contribute to strengthening U.S. industrial competitiveness. The recommendations include policy and programmatic directions. They fall short of what is ultimately needed, however. The current course of U.S. industrial R&D demands creative policies, programs, and initiatives beyond those devised and examined by the Committee. The Committee's recommendations are listed below.

1. ***Stimulate the resumption of more rapid growth of industrial R&D to match that of foreign competitors.***

   - Adopt Federal fiscal and monetary policies that encourage strategic investment in both tangible and intangible assets for R&D.

   - Encourage changes in Federal regulations and in the regulatory process to promote and facilitate technological innovation.

   - Establish a permanent R&D tax credit.

   - Put a permanent moratorium on Treasury Regulation 1.861-8 which can create a tax benefit for U.S. corporations with foreign sales that move some of their R&D to a foreign country.

2. ***Encourage a reallocation of R&D expenditures toward***

   - **nondefense R&D**

     - Establish new programs to stimulate the redirection of resources from defense to nondefense R&D.

     - Increase support for NSF strategic science and engineering research, particularly for activities that attract industrial cosupport. These activities include engineering research centers, science and technology centers, cooperative multi-user facilities, consortia, and individual investigator projects with coparticipation by industry.

- Expand programs that directly support technology transfer activities in Federal laboratories.

■ **process R&D**

- Expand and strengthen the Manufacturing Technology Centers Program and the State Technology Extension Program of the National Institute of Standards and Technology (NIST).

- Encourage substantial NSF involvement in the emerging Federal Coordinating Council for Science, Education, and Technology (FCCSET) Presidential initiative in manufacturing.

■ **engineering research**

- Encourage and assist in the expansion of Federal support of fundamental engineering research.

- Expand and strengthen NSF's Engineering Research Center Program.

■ **emerging and precompetitive technologies**

- Activate a U.S. technology policy that favors Federal R&D investment in generic precompetitive and emerging technologies important to industry.

- Encourage and assist in the expansion of Federal support of fundamental scientific and engineering research that contributes to emerging and precompetitive technologies, including the FCCSET initiatives in biotechnology, advanced materials and processing, and high-performance computing and communications.

- Expand the effectiveness, scope, and outreach of NSF's Science and Technology Centers, Industry/University Cooperative Research Centers, and other industry-related programs, and couple these programs even more closely with future industry needs.

- Further expand NIST's Advanced Technology Program.

■ **pioneering discoveries and inventions**

- Create more programmatic opportunities that encourage interaction of scientists and engineers in academia and industry to explore joint research interests with the potential for pioneering discoveries and inventions.

- Support traditional and nontraditional education programs that motivate creativity, innovation, and entrepreneurship.

3. *Improve the speed and effectiveness of moving R&D results from lab to market.*

■ Explore the feasibility of NSF supporting joint science, engineering, and management education programs that focus on the integration of technology and management for leadership of both high-tech and traditional industries.

■ Encourage NSF activities that lead to faster dissemination of knowledge and research results among researchers in academia, industry, and other sectors.

- Increase the support of science and engineering research and education programs that emphasize production systems engineering and the integration of product design and manufacturing.

4. ***Improve data quality and adequacy.***

- Carry out a systematic assessment that identifies missing information and examines the feasibility and cost of developing and tracking a set of industrial science and technology indicators that would be of value to policymakers.

Introduction

Study Purpose and Design

The preeminence of U.S. industrial science and technology can no longer be taken for granted. The growing volume of evidence suggesting a relative decline in the competitive strength of U.S. industrial science and technology is receiving widespread attention at all levels of government, in the media, and in many other public forums. One of the most closely watched signals, and one that is generating much of the alarm, is the contraction—or even the evaporation—of U.S. firms' share of global markets for an increasing number of high-technology products. Another indicator, first observed by the National Science Foundation (NSF) several years ago and now receiving considerable scrutiny, is a slowdown in the rate of growth in U.S. industry's investment in research and development, a slowdown which began in the late 1980s. Although the United States still leads in both government and nongovernment R&D spending, the recent rate of growth in U.S. investment in nondefense R&D has lagged behind that of several other industrialized nations, including Japan and (West) Germany. Additional concerns have been raised by reports from various sources, all documenting widespread consensus among industry, government, and academic officials that U.S. firms have been losing ground against foreign competitors in the advancement and commercialization of new technology. All of these trends are particularly unwelcome at a time when national prosperity is becoming increasingly dependent on the ability of the industrial sector to compete successfully in international high-technology markets.

It was these concerns that led to the establishment of the National Science Board Committee on Industrial Support for R&D. The Committee was charged by the Board with investigating the significance of recent indicators of U.S. industry's sluggish performance by:

1. Reviewing and analyzing available statistical and other information on the level, content, and quality of U.S. science and technology; and identifying what factors may be responsible for the erosion in U.S. technology leadership.

2. Reporting the major findings of its investigation, especially highlighting important barriers to improved U.S. industrial performance in high-technology markets.

3. Identifying the role NSF can play in ameliorating the problems and recommending strategies that can be pursued by NSF or other Federal agencies that will help U.S. industry compete successfully in high-tech global markets.

This report represents the culmination of the Committee's work. Note that this report is **not** intended to be a comprehensive study of U.S. international competitiveness, but rather focuses primarily on science and technology, particularly on the impact of R&D on U.S. competitive strength. The Committee recognizes that many factors besides those discussed in this report influence U.S. industrial competitiveness. Thus, improving the U.S. R&D system and the U.S. scientific and technological position will not alone be sufficient to correct all the problems of the U.S. economy or even to reverse completely the recent decline in U.S. industrial competitiveness.[1]

Part I of this report, "Analysis of Available Data," is a compilation of available statistical and other information on the current status of U.S. industrial science and technology. It also contains the major results of a survey, "Potential Causes for the Erosion in U.S. Technology Leadership," conducted in conjunction with the Industrial Research Institute (IRI). The purpose of this survey was to obtain the opinions of leading industrial R&D officials to assist the Committee in determining what factors are adversely affecting U.S. technological competitiveness.

The Committee also sought the expertise of several individuals well known for the research they have conducted in this area.

- Dr. Alden S. Bean gave a presentation on his study of changes taking place in U.S. corporate laboratories.

- Dr. Frank Huband described the methodology and results of the Japanese Technology Evaluation Program.

- Dr. Maria Papadakis gave a presentation entitled "Linking R&D, Technology, and U.S.-Japanese Bilateral Competitiveness."

- A panel of five experts discussed their research on several industries.[2]

The Committee's analysis of the data, the IRI survey results, input from the experts, and additional staff research led to one major conclusion—that although the United States still leads the rest of the world in total scientific and engineering research expenditures, those expenditures are not translating into economic leadership in the marketplace. Moreover, the ability of lawmakers and policymakers to understand and address this issue is made much more difficult by incomplete and often inadequate data. Part II of this report, "Recommendations," is devoted to identifying areas in which NSF and other Federal agencies (e.g., the Department of Commerce) may have leverage and to the presentation of specific recommendations aimed at strengthening U.S. technological competitiveness.

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[1] A report, *Capital Choices: Changing the Way America Invests in Industry,* recently released by the Council on Competitiveness, is a penetrating new study of the American system of allocating investment capital and its effect on U.S. industrial competitiveness. Its findings are much broader than, but entirely consistent with and supportive of, the present report.

[2] Members of the panel were Dr. W. Edward Steinmueller (Deputy Director, Center for Economic Policy Research, Stanford University); Dr. Kenneth S. Flamm (Senior Fellow, the Brookings Institution); Dr. David C. Mowery (Associate Professor of Business and Public Policy, Walter A. Haas School of Business, University of California, Berkeley); Dr. Candace Howes (Assistant Professor, Department of Economics, University of Notre Dame); and Dr. Henry Grabowski (Chairman, Department of Economics, Duke University).

Major Findings

After evaluating and synthesizing the information presented in part I of this report, the Committee narrowed the scope of its investigation, to focus its recommendation on four major findings. A brief review of these findings and the evidence supporting them follows.

1. ***The real rate of growth in U.S. industrial R&D spending has declined since the late 1970s and early 1980s. In addition, the Nation's position has deteriorated relative to that of its major international competitors whose investment in nondefense R&D has been growing at a faster pace than U.S. nondefense R&D since the mid-1980s.***

   - Domestic industrial R&D expenditures slowed from an average annual growth rate of 7.5 percent (constant dollars) during 1980-85 to only 0.4 percent during 1985-91. The federally supported portion of these expenditures dropped from a growth rate of 8.1 percent to -1.7 percent over these two periods; industry's own support dropped from 7.3 percent to 1.3 percent.

     Almost all major R&D-performing industries contributed to this reduced growth rate.

   - Since 1985, U.S. growth in both total and nondefense R&D expenditures has been less than that of many of its major industrial competitors.

   - The United States now trails Japan and (West) Germany, its strongest competitors, in nondefense R&D spending as a percentage of gross domestic product (GDP).

2. ***The allocation of U.S. R&D expenditures is not optimal.***

   - The balance between defense and nondefense expenditures is disadvantageous compared to that of foreign competitors.

     International data for defense and nondefense components of total R&D expenditures (not industrial alone) as a percentage of GDP can be compared. Using six countries—Japan, (West) Germany, France, the United Kingdom, Italy, and Sweden—as a benchmark, the United States in 1989 spent almost as much as they did on total R&D, but 25 percent less on nondefense R&D.

     This imbalance has been deteriorating: the fraction of U.S. R&D expenditures on nondefense decreased slightly (from 74 to 71 percent) during the 1980s, while that of the competitor group increased (from 90 to 92 percent). Thus, during the 1980s, these six competitors moved from being 22 percent ahead of the United States in nondefense R&D expenditures to being 34 percent ahead. This increase has been driven largely by Japan's huge growth in nondefense R&D spending; today, Japan spends about 3 percent of its GDP on nondefense R&D, compared to 1.9 percent for the United States.

- Too little is spent on process-oriented R&D.

  Several studies have found that U.S. industrial R&D is weighted much more heavily toward product technology rather than process technology. U.S. firms also allocate a disproportionately small share of their R&D budgets to the search for new and/or improved processes compared to their Japanese counterparts.

- Inadequate effort is devoted to fundamental engineering research.

  The rapid conversion of ideas into products and processes requires command of an ever-expanding engineering knowledge base. Yet there is an insufficiently broad and deep fundamental engineering research base on which to build.

- There is insufficient emphasis on emerging and precompetitive technologies.

  In the IRI survey, industry's "reluctance to invest in new enabling technologies because the R&D may be too expensive, long-term, multi-industry, and interdisciplinary" received the largest number of first place rankings as a factor adversely affecting U.S. industry's ability to compete in global markets for high-technology products under the major category of *technology management practices*.

- The United States faces an emerging risk of losing its traditional strength in pioneering discoveries and inventions.

  Most pioneering advances of the past that have created the basis for new industries have originated in either the corporate laboratories of private firms or in research universities. Both of these institutions are under severe stress today.

3. ***U.S. expenditures are not as effective as they should be in producing needed results.***

- The U.S. competitive position in important, technologically based industries is deteriorating.

  The once strong across-the-board U.S. position of a decade ago has deteriorated substantially. U.S. industry has already lost its leadership in several technologies that are critical to industrial performance, and is weak or losing competitive strength in others.

- The U.S. time horizon has become too short, and the Nation's business decisions tend not to be based on strategic technological considerations.

  In large corporations, effort is shifting away from central laboratories toward division-level effort with greater emphasis on risk minimization to meet the needs of today's customers; emphasis is also shifting away from new markets toward existing markets.

- U.S. R&D is not translated into beneficial economic and social results fast enough.

  Many companies trail their foreign rivals in the commercialization of new technology. In many U.S. industries, development of new products proceeds at a much slower pace than in other countries.

4. ***The current information base on industrial science and technology is inadequate: it has gaps, is questionable in parts, and does not provide enough detail to meet the needs of policymakers.***

Part I
Analysis of Available Data

Introduction

Numbers generated by the National Science Foundation (NSF) and other sources seem to indicate that U.S. industrial R&D spending stagnated in the late 1980s. NSF survey data show little real growth in industrial R&D spending after 1985, compared to the preceding 10-year period.[1] (See figure 1 and table A-1.) These time series data, however, provide an incomplete assessment, and are only one of several statistical indicators of the health of science and technology in U.S. industry.[2] Other available statistics need to be examined, including ratios measuring "R&D intensity," and comparisons of U.S. R&D expenditures with those of other countries.

In addition to data collected through NSF and other surveys, information comparing the United States with other countries in the advancement of selected technologies is available from several research projects, e.g., the Japanese Technology Evaluation Center (JTEC). These investigations yield qualitative rather than quantitative information and provide valuable insight into the strengths and weaknesses of U.S. science and technology vis-à-vis those of other countries.

This part of the report first examines three types of information useful in diagnosing the state of U.S. industrial R&D. These measures are

- **input measures,** including aggregate levels of R&D expenditures and R&D intensity ratios;
- **R&D content,** or the allocation of R&D resources; and
- **output measures,** including findings from the studies mentioned above.

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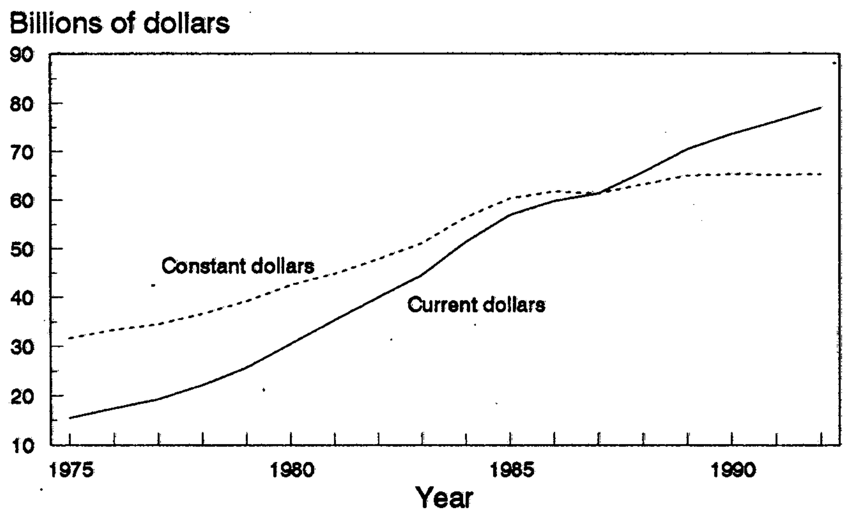
[1]Industrial R&D expenditure data cited in this section of the report (unless otherwise indicated) refer to funds supporting R&D work performed within company facilities in the United States from all sources, except the Federal Government. These sources may include other companies, research institutions, colleges and universities, other nonprofit organizations, and state and local governments, as well as companies' own funds. Company-financed R&D not performed within the company is excluded. Note that foreign companies' R&D expenditures in the United States are also included. The R&D growth rate would be even lower if monies spent by foreign companies in the United States were subtracted from the total.

[2]Comprehensive quantitative measures of investment in science and technology do not exist. Therefore, the total amount of funds spent on R&D is commonly used as a surrogate measure.

Figure 1. Company-funded industrial R&D



The rate of increase in company-funded industrial R&D in the U.S. slowed during the late 1980s.

Notes: Company-funded R&D includes funds for industrial R&D work performed within company facilities in the U.S. from all sources except the Federal Government. The 1987 GDP implicit price deflator was used to convert current to constant dollars. (See table A-1.)

Sources: NSF, Survey of Industrial Research and Development and Industrial Panel on Science and Technology

Because the Committee felt its evaluation would not be complete without input from leading industrial R&D officials, the last section of the chapter contains a summary of the main results of a survey on "Potential Causes for the Erosion in U.S. Technology Leadership." This survey was used to obtain the viewpoints of leading industrial R&D officials. Specifically, corporate R&D directors were asked to rank series of factors thought to contribute to a decline in U.S. technological competitiveness. A fuller description of the survey results is in appendix B.

Although these data on R&D are useful in diagnosing the state of U.S. industrial R&D, taken together, they still leave unanswered questions. Compounding this dilemma are gaps and deficiencies in the quantity and quality of information collected and available on industry's investment in, and commitment to, the advancement of science and technology.

Input Measures of Industrial R&D Performance

R&D Expenditures in U.S. Industrial Laboratories

U.S. industrial firms finance R&D performed in their own domestic laboratories and also support R&D conducted in other locations, including company-owned facilities in other countries, colleges and universities, and other nonprofit organizations. Aggregate levels of R&D funding in U.S. industrial laboratories are described below.

The National Science Foundation is the major source of statistical data on U.S. industry's investment in research and development. Its information is collected with the annual Survey of Industrial Research and Development; this survey has been conducted for NSF by the U.S. Bureau of the Census for more than 30 years.[3] NSF supplements the data collected through the industry R&D survey with information obtained from annual polling of its Industrial Panel on Science and Technology, which is comprised of at least 100 industry R&D officials.

Industry is the source of about one-half of the funds spent on R&D in the United States. In 1991, industrial firms spent $76.4 billion in company funds on R&D performed in U.S. laboratories. (See table A-2.) In addition, U.S. firms spent $30.4 billion in Federal funds on R&D; this was approximately half of all Federal monies supporting R&D. Thus, industry is by far the largest performer of R&D in the United States, accounting for 71 percent of total U.S. R&D performance

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[3]Data collected with this survey are published annually in an NSF series, *Research and Development in Industry*. They are also published in other NSF reports, including *National Patterns of R&D Resources*, and in the National Science Board series, *Science & Engineering Indicators*. During its investigation, the Committee was made aware of deficiencies in this time series that adversely affect the quality and usefulness of data collected with this survey. Many of these problems are identified in this section. Nevertheless, it is the best available source of statistical information on industry's performance of R&D. The Committee's recommendations for improving and increasing the collection of data on industry's investment in science and technology are included in part II of this report.

in 1991. The Federal Government accounts for 11 percent, the academic sector 15 percent, and the nonprofit sector 3 percent.[4]

During the late 1980s and into the early 1990s, company spending on R&D barely kept pace with inflation. In real terms, the average annual increase between 1985 and 1990 was only 1.6 percent; the 1990-92 increase is projected to be 0.1 percent. In contrast, real average annual increases of 6.1 percent and 7.3 percent were registered during the 1975-80 and 1980-85 periods. (See figure 2.) In all major R&D-performing industries except motor vehicles,[5] rates of growth in R&D spending in the late 1980s were significantly below those recorded in the first half of the decade. This trend is expected to continue into the 1990s. (See figure 3 and tables A-3 and A-4.)[6]

The declining growth rate has been attributed to several factors including the poor performance of the U.S. economy; poor sales, leading to lackluster profits, and resulting in a lack of funds available to expand R&D programs;[7] reactions to high-technology import competition (Scherer and Huh 1992); the spate of corporate restructuring, especially mergers, acquisitions, and divestitures, that occurred in the mid- and late 1980s;[8] and increasing support for externally performed R&D, including funding of R&D performed in U.S. companies' foreign laboratories, at universities and colleges, and by nonprofit organizations.

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[4]Total Federal R&D support amounted to $65.2 billion in 1991. Industry received 47 percent of that amount; 23 percent went to universities and colleges; 5 percent to nonprofit organizations; and 25 percent was spent in government laboratories.

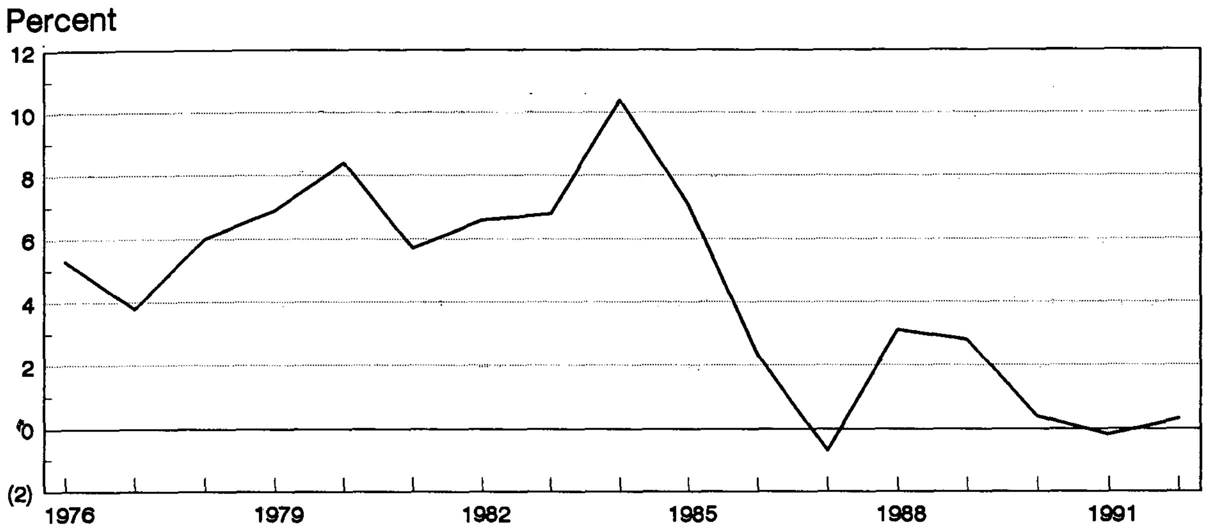
[5]Motor vehicle companies' average annual rate of growth in R&D spending increased from 1.7 percent in the early 1980s to 3.0 percent in the second half of the decade.

[6]Nonmanufacturing, or service, industries now account for approximately 9 percent of company-funded R&D performed in the United States. NSF data show more than a sixfold increase in R&D spending by this sector between 1980 and 1990, with the gain concentrated in two groups of companies: (1) computer programming and engineering services, and (2) communication services. Although many new service companies came into existence during the late 1970s and throughout the 1980s, the actual increase in R&D spending might not be as large as the data indicate, because part of the increase is probably due to improved coverage of the service sector. See Pollak (1991). Despite the apparent strength of R&D performance in the U.S. service sector, the Committee discovered that at least one industry within this group has not been doing well in terms of R&D expenditures. According to data from the Construction Industry Institute (1988), U.S. construction firms spend a total of only $50 million annually on R&D, compared to $2 billion spent by Japanese firms. See *Wall Street Journal* (1991).

[7]Findings from annual polls of NSF's Panel on Industrial Science and Technology are described in the following *Science Resources Studies Highlights*: NSF 86-314; NSF 88-311, NSF 89-310, and NSF 90-307, and special reports 91-306 and 92-306. Also, in discussing with the Committee their research on the integrated circuit and pharmaceutical industries, Drs. Steinmueller and Grabowski emphasized that increased investment in R&D is largely dependent on cash flow availability. See Grabowski (1989).

[8]The impact of mergers and other types of corporate restructuring, including leveraged buyouts, on industry's investment in R&D has not been definitively determined. Several researchers have examined various aspects of the issue, employing different approaches and methodologies that yielded different results. Among these studies are: "Corporate Restructuring and Industrial Research and Development," National Academy of Sciences, National Research Council, Academy Industry Program; "Corporate Mergers Implicated in Slowed Industrial R&D Spending" (unpublished NSF Paper); "The Impact of Corporate Restructuring on Industrial Research and Development," Bronwyn H. Hall, National Bureau of Economic Research, Working Paper No. 3216; and "LBOs, Debt and R&D Intensity," William Long, Center for Economic Studies, U.S. Bureau of the Census, and David Ravenscraft, University of North Carolina.

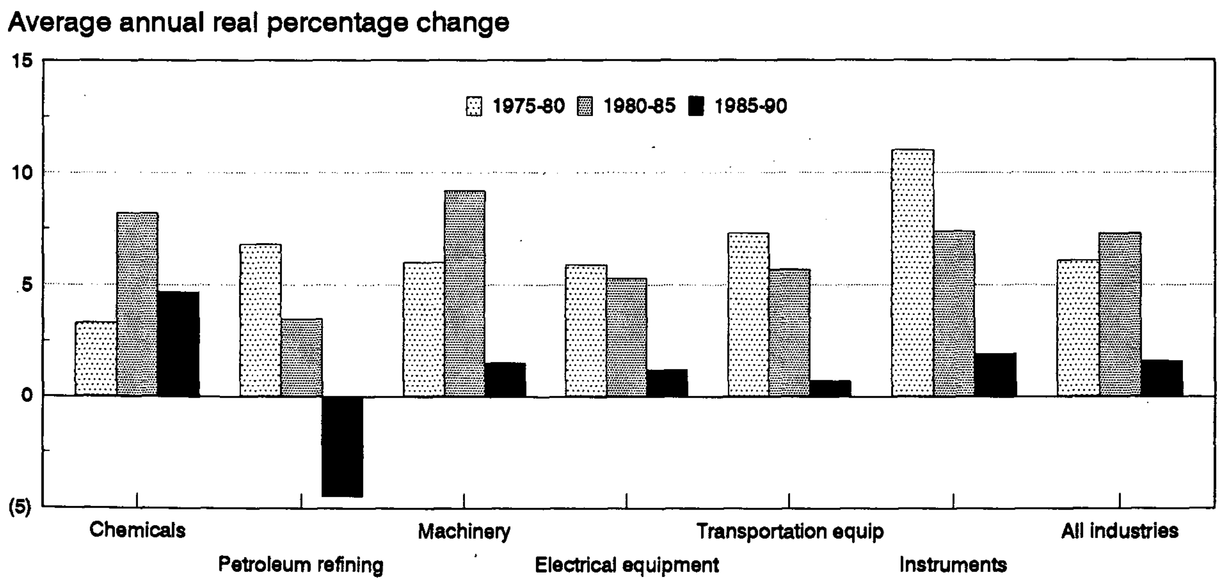
Figure 2. Real annual growth rates in company-funded industrial R&D



The annual percentage increase in company-funded industry R&D (in constant dollars) is now lower than it was 10 to 15 years ago.

Note: The GDP implicit price deflator was used to covert current to constant dollars.
Sources: NSF, Survey of Industrial R&D, and NSF Industrial Panel on Science and Technology

Figure 3. Rates of increase in company-funded industrial R&D in major R&D-performing industries



The rate of increase in company-funded industrial R&D slowed in all major R&D-performing industries during the late 1980s.

Note: The GDP implicit price deflator was used to covert current to constant dollars. See tables A-3 and A-4 for data on more narrowly defined industries.

Sources: NSF, Survey of Industrial R&D, and NSF Industrial Panel on Science and Technology

R&D Intensity

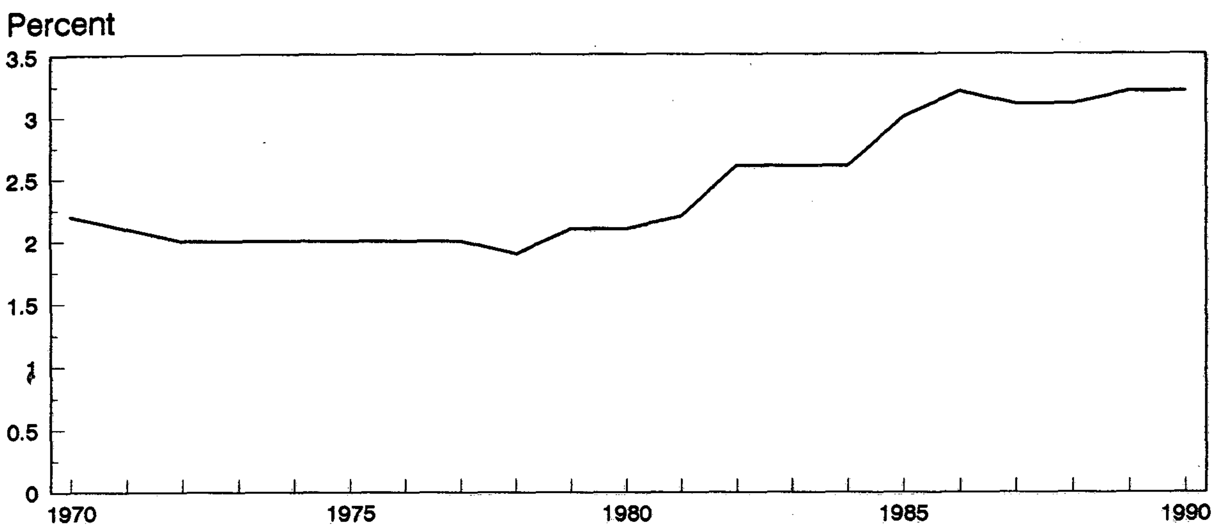
The ratio of R&D expenditures to net sales is usually used to measure R&D intensity. For all manufacturing firms performing R&D, this ratio was 3.2 percent in 1990. During the 1970s, it hovered in the 2.0-percent range, showing either no change or annual movements of only one- or two-tenths of a percentage point, then began to climb in the early 1980s. (See figure 4 and table A-5.) Between 1981 and 1982, there was an unprecedented jump in this statistic—from 2.2 percent to 2.6 percent. This 1-year increase was attributable to a 12.4-percent rise in R&D expenditures, combined with a 6.9-percent decline in net sales of R&D-performing companies during the 1981-82 recession. Another similar leap in this statistic occurred between 1984 and 1985, when R&D spending rose 9.3 percent and net sales fell 2.9 percent. The ratio has been level at about 3.2 percent during the second half of the decade when there was limited growth in R&D funding and net sales.

Other measures of R&D intensity are the ratio of R&D scientists and engineers (S&Es) to total employment in R&D-performing manufacturing companies, and the ratio of total S&Es to total manufacturing employment. These ratios increased steadily throughout the late 1980s, because employment of S&Es has been increasing at a faster pace than has overall employment in all industries. For example, there were 40 R&D S&Es per 1,000 employees in R&D-performing manufacturing companies in 1984 and 49 in 1990. (See table A-6.) During this period, R&D performing companies' total employment increased 8.4 percent, while employment of R&D S&Es increased 19.4 percent.

Similarly, the ratio of all S&Es to total manufacturing employment rose from 37 in 1980 to 51 in 1989 (NSB 1991, appendix table 3-1). Between 1980 and 1989, total employment in the manufacturing sector declined about 4.2 percent. The decline in total manufacturing employment, combined with S&E employment growth, resulted in a substantial increase in the S&E proportion of the manufacturing workforce.

Although degree of R&D intensity varies widely across industries (see table 1), these statistics have either been steady or gradually increasing in almost every industry over the past decade. (See figures 5 and 6 and tables A-5 and A-6.)

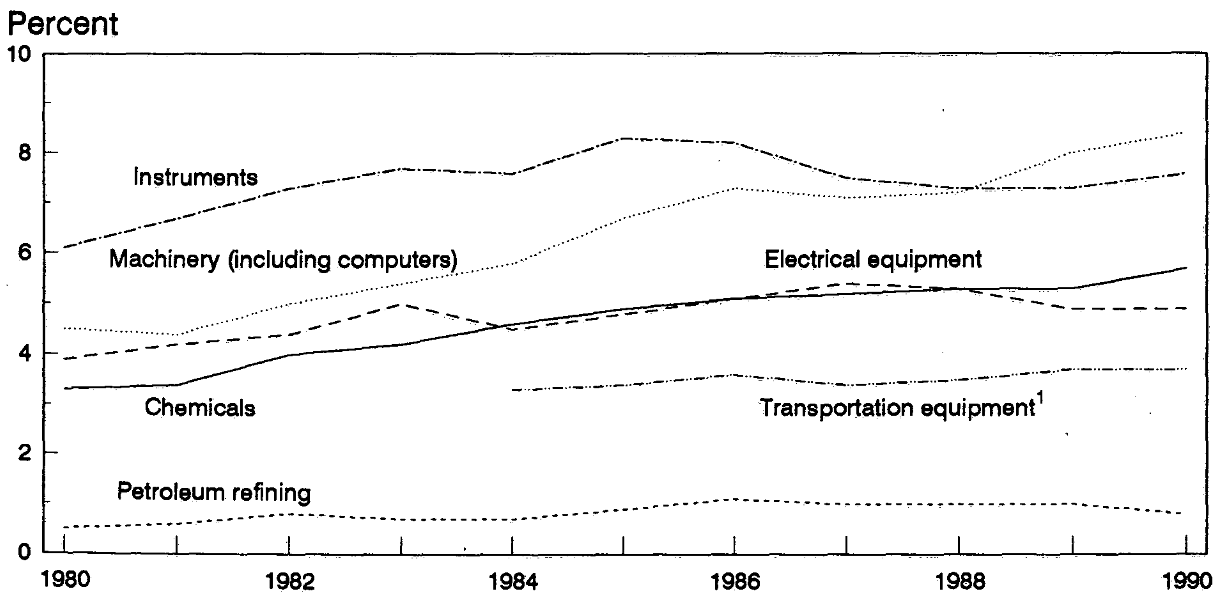
Figure 4. Company-funded industrial R&D as a percentage of net sales



Company R&D funds as a percentage of net sales increased from 2 percent in the 1970s to 3 percent in the late 1980s.

Note: See table A-5.
Source: NSF, Survey of Industrial R&D

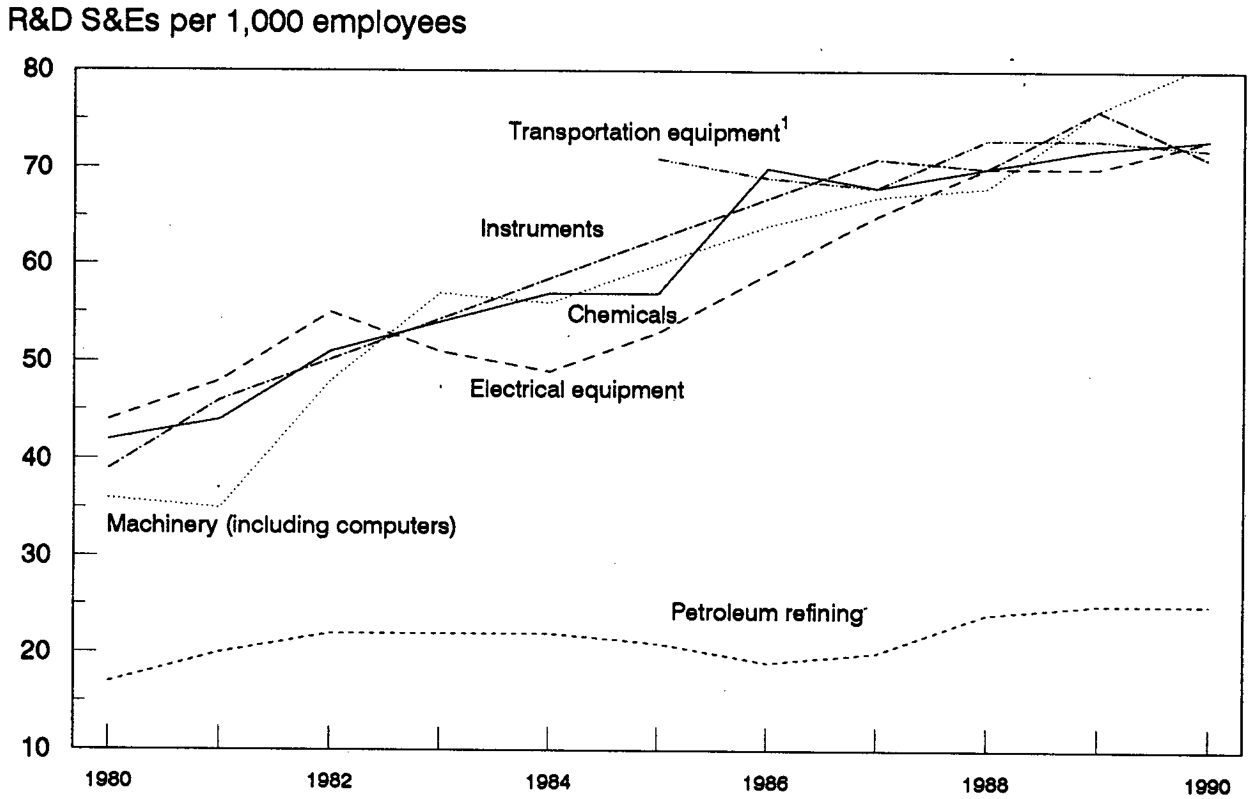
Figure 5. Company-funded industrial R&D as a percentage of net sales for major R&D-performing industries



R&D spending as a percentage of net sales was higher in 1990 than in 1980 in all major R&D-performing industries.

[1] Data unavailable for earlier years.
Note: See table A-5.
Source: NSF, Survey of Industrial R&D

Figure 6. The R&D S&E proportion of the workforce in major R&D-performing industries



The R&D S&E proportion of the workforce increased in all major R&D-performing industries during the 1980s.

[1]Data unavailable for earlier years.

Note: See table A-6.

Source: NSF, Survey of Industrial R&D

Table 1. Industry segments with the highest and lowest company R&D funds/net sales ratios: 1990
(Percent)

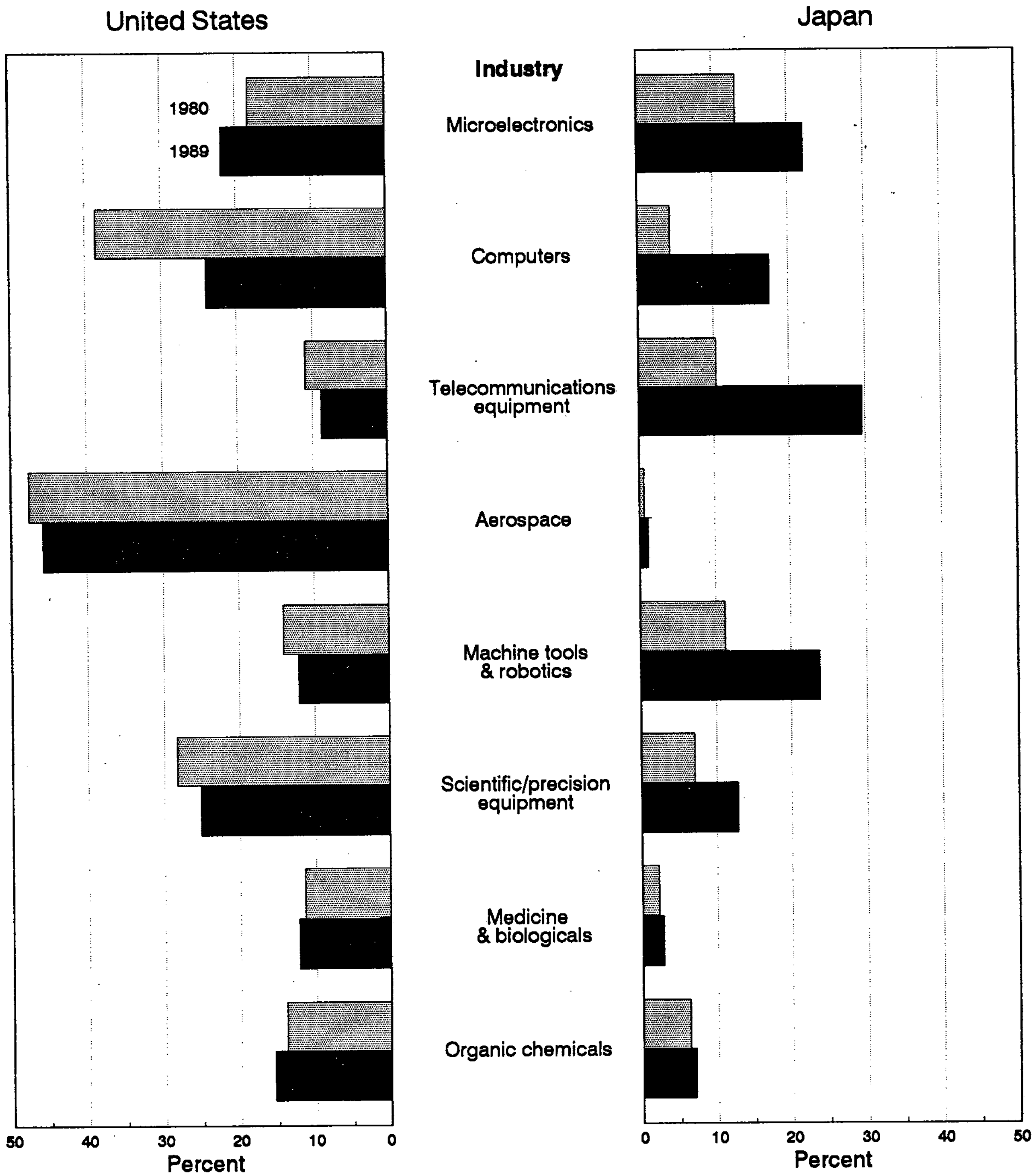
Industry segment	R&D/sales
Highest	
Computers	15.4
Drugs and medicines	9.8
Scientific and mechanical measuring instruments	9.4
Electronic components	8.6
Optical, surgical, photographic, and other instruments	6.9
Communication equipment	4.9
Lowest	
Petroleum refining and extraction	0.8
Paper and allied products	0.8
Lumber, wood products, and furniture	0.7
Ferrous metals and products	0.6
Food and tobacco products	0.5
Textiles and apparel	0.4

Source: NSF, Survey of Industrial Research and Development

R&D Content

Has the allocation of R&D resources been less than optimal? Data comparing U.S. R&D spending to that of other countries reveal several striking differences that may help explain why U.S. industry is losing ground in developing high-technology products to compete in world markets. Figure 7 and table A-7 show changing U.S. and Japanese shares of global exports for eight industries. The U.S. share has been eroding in five of the industries included on these charts—computers, telecommunication equipment, aerospace, machine tools and robotics, and scientific/precision equipment—but not in the other three—microelectronics, medicine and biologicals, and organic chemicals. The most dramatic change depicted in figure 7 occurred in worldwide exports of computers: the U.S. share of the global market dropped from 39 percent in 1980 to 24 percent in 1989. Table A-8 (prepared by Dr. Kenneth Flamm) shows the United States' declining share of sales of information systems. In contrast, the Japanese global share increased in all industries shown on these charts; for six of these industries—microelectronics, computers, telecommunication equipment, machine tools and robotics, and information systems—the gains are striking.

Figure 7. U.S. and Japanese shares of global exports for selected high-technology industries



The U.S. share of global exports has declined in several industries, while Japan's has increased.

Note: See table A-7.

Source: CIA Handbook of Economic Statistics, 1990

U.S. R&D Investment Compared to That of Other Countries

In absolute terms, the United States spends more than twice as much on R&D as does Japan,[9] 4½ times as much as (West) Germany, and over 6 times as much as France and the United Kingdom. In relative terms, however, the picture is considerably different. Total U.S. R&D spending as a percentage of gross domestic product (GDP) lags behind spending in Japan and (West) Germany.[10] While the U.S. level of 2.7 percent in 1990 is comparable to its 1970 level (2.6 percent), Japan's proportion grew from 1.9 to 3.1 percent, and (West) Germany's proportion increased from 2.1 to 2.8 percent. (See figure 8 and table A-9.)

The prominence of defense in U.S. R&D strengthens the finding of a U.S. lag of investment in R&D. If just nondefense R&D is considered, the United States invests 1.9 percent of its GDP in R&D, compared to 3.0 percent for Japan and 2.7 percent for (West) Germany. (See figure 9 and table A-10.)[11] Perhaps the most striking indicator of Japan's escalating strength in science and technology is depicted in figure 10. Japan's investment in nondefense R&D has been increasing dramatically.

These data suggest that government plays a more prominent role in the U.S. R&D system—and in particular, in the U.S. industrial R&D system—than it does in the systems of its major trading partners. But if the U.S. Government invests more heavily in R&D, it directs that investment almost entirely toward government missions such as national security, space exploration, and health rather than to industrial purposes.

Defense accounts for about three-fifths of U.S. Government R&D spending and two-thirds of the growth in that spending between 1980 and 1992.[12] In contrast, in 1989, 9 percent of Japan's government R&D spending went to defense; in (West) Germany, this proportion was 19 percent,

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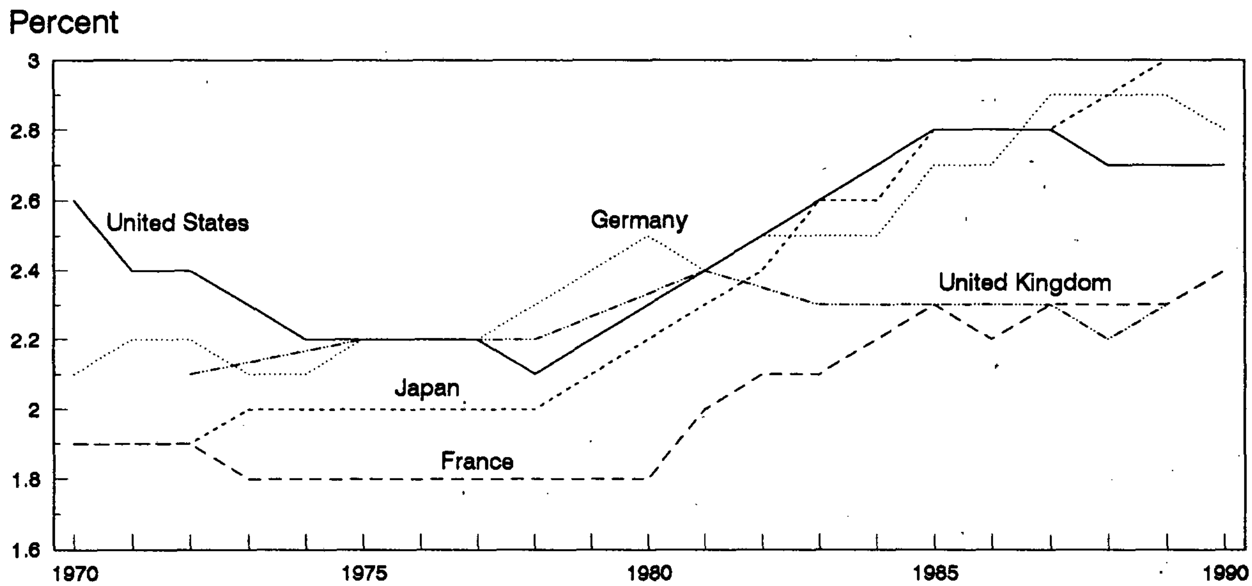
[9] A controversy recently surfaced over international comparisons of R&D expenditures—i.e., which country is spending more on R&D, the United States or Japan? The answer depends on what formula is used to convert yen to dollars. If currency exchange rates are used, Japanese industrial firms appear to be spending more on R&D than U.S. firms. NSF follows the international, long-established convention of using purchasing power parities to convert yen to dollars. Therefore, the data in this report show U.S. firms spending considerably more on R&D than Japanese firms (although expenditures by the latter have been growing at a much faster rate). For discussions of this issue, see *National Journal* (1992) and *New York Times* (1992).

[10] The Federal Government is now using gross domestic product instead of gross national product because GDP measures production of goods and services in the United States only, thus providing a more precise indicator of the country's economic condition.

[11] In 1989, government funding of R&D accounted for 45 percent of total U.S. R&D, 19 percent of R&D in Japan, 33 percent in (West) Germany, 49 percent in France, and 37 percent in the United Kingdom. Government funds accounted for 31 percent of U.S. industrial R&D, but only 2 percent of industrial R&D in Japan, 11 percent in (West) Germany, 21 percent in France, and 20 percent in the United Kingdom.

[12] Growth in Federal R&D spending slowed significantly after 1987. Defense, as a percentage of total federally funded R&D, reached a peak of 69 percent in 1986 and 1987. Since then, the share of defense-related R&D outlays has fallen to (an estimated) 59 percent in 1992.

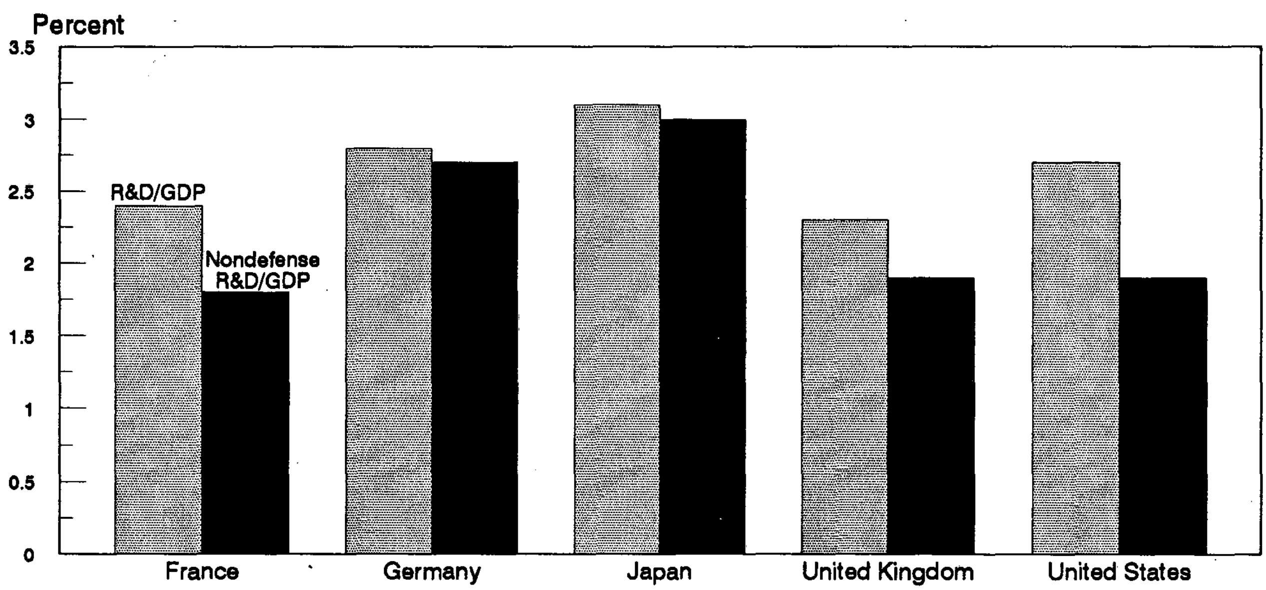
Figure 8. International comparisons of R&D expenditures as a percentage of GDP



Japan and Germany have surpassed the U.S., in terms of R&D/GDP.

Note: See table A-9.
Sources: NSF, Organisation for Economic Cooperation and Development, International Monetary Fund, and national sources

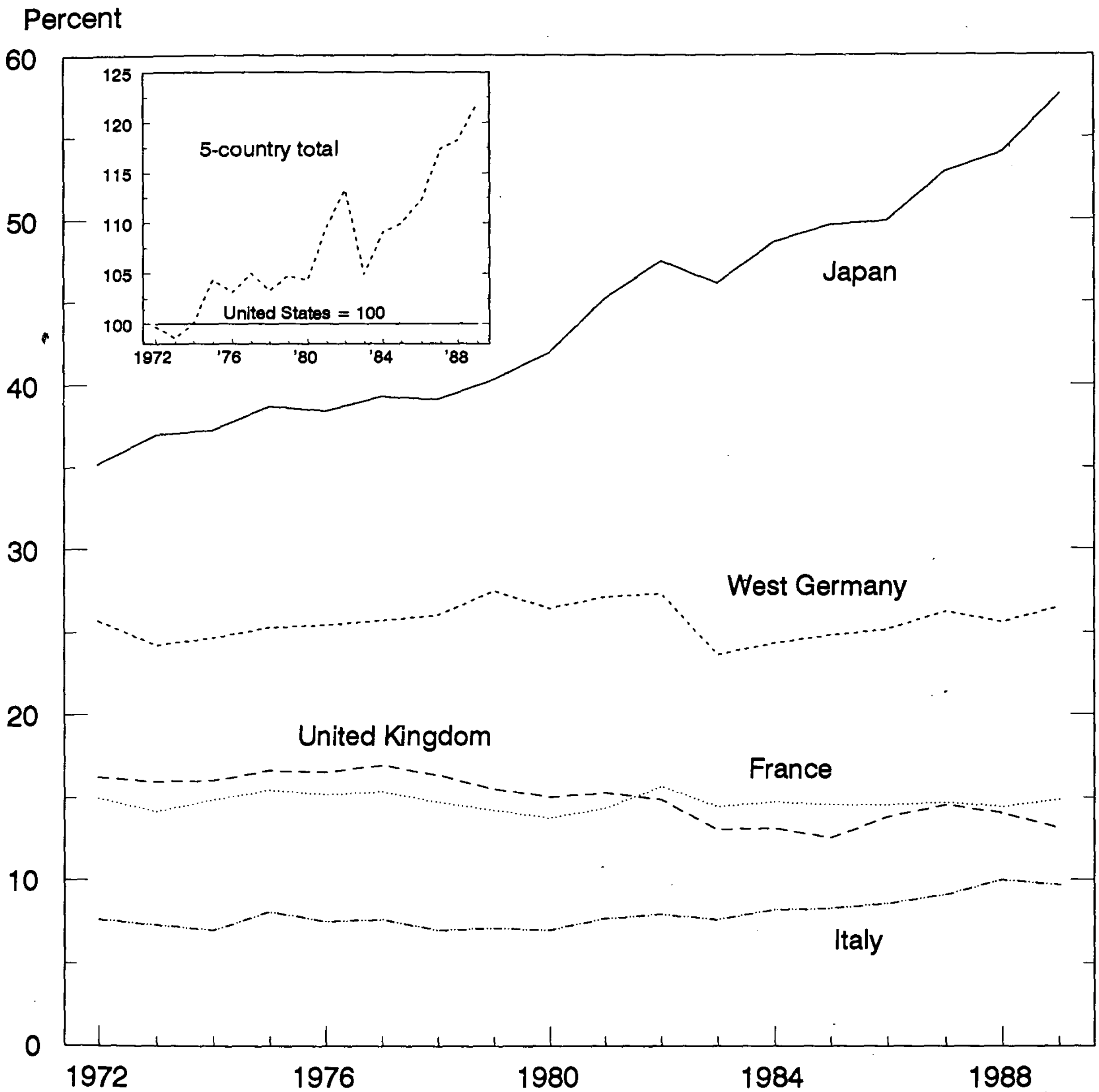
Figure 9. International comparisons of total and nondefense R&D as a percentage of GDP



The U.S. trails Japan and Germany in nondefense R&D/GDP.

Note: See table A-10.
Sources: NSF, Organisation for Economic Cooperation and Development, International Monetary Fund, and national sources

Figure 10. Nondefense R&D: Foreign spending as a percentage of U.S. spending



Japan's investment in nondefense R&D has been growing at a much faster pace than U.S. investment in nondefense R&D

Note: See table A-10.

Sources: NSF, Organisation for Economic Cooperation and Development, International Monetary Fund, and national sources.

in France, 42 percent; and in the United Kingdom, 55 percent. (See figure 11 and table A-11.) Thirteen percent of the U.S. Government R&D budget is directed at health (compared to between 4 and 6 percent for the trading partners); 7 percent to civilian space applications (roughly comparable to [West] Germany and France, and higher than the United Kingdom, but lower than Japan's 11 percent); and 4 percent to energy (comparable to the United Kingdom and France, but much lower than Japan's 39 percent and lower than [West] Germany's 9.5 percent).

Except for a few programs—including some in the Department of Commerce's National Institute for Standards and Technology (NIST) and arguably, a small proportion of NSF's budget—almost none (0.2 percent) of the U.S. Federal R&D budget is directed at R&D of direct relevance to commercial technology. In the other countries, government support of commercially oriented R&D is considerably higher, ranging from 8 percent in Japan[13] to 19 percent in (West) Germany.

Government-sponsored R&D has, however, played a major role in U.S. industrial competitiveness in some instances. The billions of dollars for research conducted in National Institutes of Health laboratories, although not specifically earmarked to help U.S. firms build competitive advantage, nevertheless contributed to the leadership position of the U.S. pharmaceutical and biotechnology industries.

In the past, byproducts or spinoffs from government mission R&D had a significant impact on U.S. industrial technology. The jet engine, computer, and integrated circuit received a jumpstart in the United States precisely because R&D funding was linked to defense missions. Defense needs drove development of these technologies that then found widespread application in the commercial sphere. But spillover benefits from defense-oriented R&D no longer seem nearly as strong as they used to be (Nelson 1990 and Alic et al. 1992). In many technology areas, performance requirements of military and commercial systems have diverged dramatically since the days of the postwar technology spinoffs. According to Kenneth Flamm (1988), "Relying on accidental spillover from military R&D may have worked out just fine in an era in which the U.S. had no serious technological competitors. That was also a time when the sums the U.S. spent on technology vastly exceeded all foreign expenditures, a time that has clearly passed."

Whether the heavy role of government in R&D is, on balance, now a source of advantage or disadvantage is open to debate. In fact, an opposite perspective is gaining in popularity—many are now claiming that "the military sector increasingly builds on civilian [technological] development[s], rather than the other way around" (Bloch 1991).[14]

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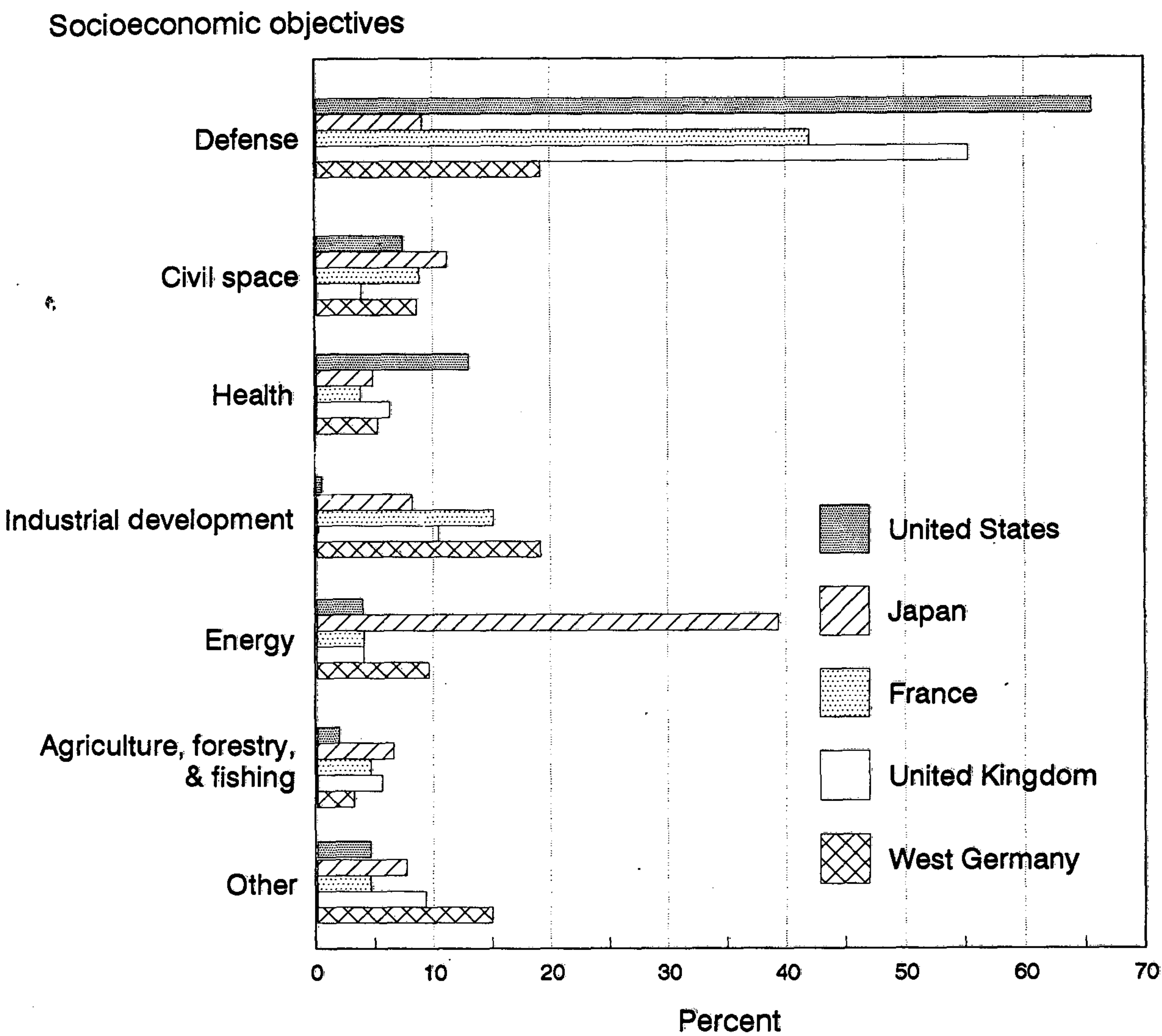
[13]Although direct government support of commercial technology development appears to be relatively low in Japan, the Japanese Government provides extensive indirect support, including various tax incentives and low-interest loans to industrial firms to encourage them to invest in R&D and commercialize new technology.

[14]See Council on Competitiveness (1991), table 4, "The Defense Department's Changing Role in Technology Development." The advantages of DOD-supported technology in the 1950s, contrasted with the disadvantages apparent in today's DOD-supported technology development, are listed in this table.

Figure 11. International comparisons of governmental R&D budget priorities



U.S. R&D budget priorities differ from those of its trading partners.

Note: See table A-11.
Sources: NSF, Organisation for Economic Cooperation and Development, and national sources for Japan

In general then, the U.S. R&D system exhibits a strong presence by the Federal Government in industrial R&D, but that R&D is oriented toward government rather than commercial objectives. For example, in manufacturing, "many of the DOD- and NASA-funded efforts in robotics deal with mobility and navigation, the areas deemed least important in a recent Robot Industries Association survey of American manufacturers" (Hanifin 1988).

This issue was also addressed by a Presidential Advisory Panel formed to assess the Nation's effort in high-temperature superconductivity. In late 1988, the panel concluded the following (Committee to Advise the President on High Temperature Superconductivity 1988, p. 8).

> While there is a high level of activity in U.S. industry today, much of it is scattered and in monitoring groups and is unlikely to survive in what we believe will be a long distance race. And while there is a high level of activity by the U.S. government today both in government labs and in support of universities, the work is primarily structured around government rather than commercial applications.
>
> In contrast the Japanese government laboratories have a long tradition of materials work done closely with industry, and the Japanese government has put in place . . . a structure that will support, coordinate and sustain the various individual industrial efforts in Japan as the Japanese companies work their way through the early stages of this new technology and look for applications.

U.S. industry's inability to commercialize technology rapidly and effectively is the focus of almost all recent literature on competitiveness. This failing is frequently attributed to a lack of attention to improvements in process technology. Studies on individual industries conducted by the MIT Commission on Industrial Productivity revealed "that the lax attitude toward process improvement is widespread in U.S. companies but not universal" (Detouzos et al. 1989, p. 76).

Edwin Mansfield of the University of Pennsylvania found that U.S. companies differ significantly from their Japanese counterparts in R&D organization and mix of activities. In particular, Mansfield's research revealed striking differences in emphasis on process technology between U.S. and Japanese firms (Mansfield 1988b).

> The American firms . . . devote about two-thirds of their R&D expenditures to improved product technology (new products and product changes) and about one-third to improved process technology (new process and process changes). Among the Japanese firms . . . the proportions are reversed, two-thirds going for improved process technology and one-third going for improved product technology.

Results from another study show U.S. companies devoting only 19 percent of their R&D budgets to process innovation (Caravatti 1991).

Mansfield's research provides evidence of another significant difference between U.S. and Japanese R&D investment. He found that nearly one out of every two dollars spent on R&D by U.S. companies is used to support projects seeking new products and processes. In contrast, a smaller percentage—approximately one-third—of Japanese R&D expenditures is devoted to discovering new products and processes, while the remainder is directed toward perfecting existing technologies (Mansfield 1988a, table 4).

How Are U.S. Firms Adjusting to Meet Increasing Foreign Competition?

Alden S. Bean's 1988 survey of R&D executives from 140 firms affiliated with the Industrial Research Institute (IRI)[15] provides some insight into this issue (Bean 1989).

The survey results showed that the distribution of effort between relatively centralized corporate laboratories and technical centers and relatively decentralized division and group labs changed markedly during the 1980s. According to the survey respondents, there was a shift away from centralized R&D and toward more divisional R&D. This trend implies a change in lead times as well as the mix of R&D actually undertaken by U.S. firms.

The survey revealed a shift in emphasis toward the "customer" end of the pipeline in all industrial R&D laboratories—the distinction between central and division work has been fading. A strong drive is under way to make central laboratories more responsive to business units. Thus, a greater emphasis is being placed on risk minimization; R&D has a more short-term focus: to meet the needs of today's customers.

Two important changes appear to have occurred in the 1980s, both of which are consistent with the trend away from corporate, central labs.

1. In the 1970s, exploratory research and research aimed at complying with government regulations were emphasized. In the 1980s, these two types of research, while still viewed as significant, were considered less important than research aimed directly at product and process innovations for commercial advantage.

2. Among corporate or central R&D labs, new product and process development was emphasized during both the 1970s and the 1980s. Where there has been a change is in the relative emphasis on existing markets as opposed to new markets. "Central labs appear to have become more involved in some form of applications development research for existing markets in the 1980s. This appears to be a striking contrast to their role in the 1970s, when they emphasized diversification and programs for new markets over programs for existing markets" (Bean 1989).

The survey also found that:

1. Cost-based factors and efficiency considerations determine whether R&D is performed in central or other research facilities. For example, the high cost of using supercomputing

[15] U.S.-based firms in the IRI fund roughly 85 percent of total U.S. industrial R&D. See IRI (1992).

facilities requires performing work using a supercomputer in a central research laboratory.[16]

2. The advantages of centralization include intellectual synergy and cost-effective use of facilities; the disadvantages are management difficulties in transferring research technology from the central laboratory to other parts of the company.

3. Companies under less competitive pressure are able to devote more resources to central research laboratories than those facing intense foreign and domestic competition.

Data from NSF's annual industry R&D survey appear to confirm the findings from Bean's survey; they show basic research, as a percentage of total R&D expenditures, declining in the late 1980s from 5.8 percent in 1986 to 4.3 percent in 1990, applied research staying about the same (around 25 percent of the total), and development rising slightly.[17] In addition, a recent survey of chief executive officers (CEOs) representing electronics companies revealed a shift in that industry from basic to applied research. According to the respondents, the change is largely attributable to an increasing emphasis on accommodating customers' needs in product development (*Electronic Business* 1991).

R&D Output

Several recent studies have yielded information helpful in examining and evaluating the quality and effectiveness of U.S. industrial R&D and in comparing U.S. research, applications, and commercialization of new technologies with those of other countries. Unfortunately, there has been only a scattering of attempts to quantify output indicators—e.g., degree of innovation and speed of product development—and the feasibility of collecting such data has yet to be established.[18] Thus, almost all of the information available on R&D output is derived from the observations of industrial, government, and academic experts.

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[16]This situation is changing rapidly because of improved network access to supercomputers.

[17]Two problems seriously affect the quality of NSF's data on industry-performed basic research, applied research, and development: (1) lack of response to the item on the survey questionnaire, and (2) respondents' varying interpretations of the definitions of the three categories. The first problem is far more serious than the second. Until 1986, NSF estimated that industry spent 3 to 4 percent of its own funds on basic research and slightly over 20 percent on applied research; about three-fourths of the monies supported development of new products and processes. NSF and Census staff refined the methodology used for estimating nonresponse beginning with the 1986 data. These revisions resulted in basic research accounting for 4 to 5 percent, applied research about 25 percent, and development about 70 percent of industry's R&D expenditures. See NSF (1990a and 1990b).

[18]One such attempt was made several years ago; the results appeared in an unpublished report, "A Survey of Industrial Innovation in the United States," prepared by Audits and Surveys for NSF's Division of Science Resources Studies.

Deterioration of U.S. Technology Leadership Position

There have been at least three recent efforts to evaluate and rate the quality of other nations' research and advancement in selected technologies vis-a-vis those of the United States: (1) the Japanese Technology Evaluation Center;[19] (2) a Commerce Department evaluation, *Emerging Technologies: A Survey of Technical and Economic Opportunities*; and (3) a Council on Competitiveness report, *Gaining New Ground: Technology Priorities for America's Future*. The Committee did not independently assess the U.S. position relative to other nations in technologies so it cannot substantiate the validity of these assessments. Moreover, the studies differ slightly in some details. Nevertheless, the general conclusion emerges strongly and repeatedly: a decline in relative strength of U.S. industrial technology.

The purpose of the **JTEC project** is to bring together experts from industry, universities, and the government to evaluate the strengths and weaknesses of both the Japanese and U.S. systems that facilitate and hinder the exploration and commercialization of technology. Findings of these studies are based on the experts' perceptions of performance in each of the examined technologies.

The Japanese and U.S. approaches to the performance of research and development have traditionally differed in several major respects. In the United States there has been greater emphasis on basic research, while in Japan the emphasis tends to be on focused development work with specific commercial applications. Also, academic institutions have different functions within the scientific and technological apparatus of each country.

Factors responsible for the high quality of science and technology in Japan appear to be the practices of sending students and professionals to other countries for study, Japan's longer time horizon, lower capital costs due to higher savings rates, Japanese manufacturing excellence and attention to engineering, and—in some industries—the role of the Ministry of International Trade and Industry (MITI). MITI has been particularly successful in inducing companies to translate generic into proprietary research, thus facilitating the development of new and/or improved products (Gamota and Frieman 1988, pp. 5-9).

One of the weaknesses of the Japanese system is that because it is customary to employ workers for life, Japanese companies have difficulty acquiring outside expertise. Existing staff must be used to gain access to new developments.

Another conclusion from these studies is that numbers on Japanese investment in certain technologies often understate the actual amount of investment, because several costs (which are included in U.S. calculations) may be excluded from the figures compiled in Japan.

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[19] J-TECH became JTEC in February 1989 when management of the program was transferred from Science Applications International Corporation to Loyola College in Maryland. J-TECH stood for Japan Technology; JTEC stands for the Japanese Technology Evaluation Center.

Completed and ongoing JTEC studies are listed in table 2. These studies cover a large number of technologies including computer sciences, advanced computing, opto- and microelectronics, mechatronics, telecommunications, biotechnology, advanced materials, advanced sensors, superconductivity, space propulsion, space robotics, and nuclear power.

Table 2. Japanese technology evaluation reports

Report title	Date
JTECH Panel Report on Computer Science in Japan	Dec. 1984
JTECH Panel Report on Opto- and Microelectronics	May 1985
JTECH Panel Report on Mechatronics in Japan	May 1986
JTECH Panel Report on Biotechnology in Japan	May 1986
JTECH Panel Report on Telecommunications Technology in Japan	May 1986
JTECH Panel Report on Advanced Materials	May 1986
JTECH Panel Report on Advanced Computing in Japan	Dec. 1987
JTECH Panel Report on CIM and CAD for the Semiconductor Industry in Japan	Dec. 1988
JTECH Panel Report on the Japanese Exploratory Research for Advanced Technology (ERATO) Program	Dec. 1988
JTECH Panel Report on Advanced Sensors in Japan	Jan. 1989
JTECH Panel Report on High Temperature Superconductivity	Nov. 1989
JTECH Panel Report on Space Propulsion in Japan	Aug. 1990
JTECH Panel Report on Nuclear Power in Japan	Oct. 1990
JTECH Panel Report on Advanced Computing in Japan	Oct. 1990
JTECH Panel Report on Space Robotics in Japan	Jan. 1991
JTECH Panel Report on High Definition Systems in Japan	Feb. 1991
JTECH Panel Report on Advanced Composites in Japan	March 1991
JTECH Panel Report on Construction Technologies in Japan	June 1991
JTECH Panel Report on X-Ray Lithography in Japan	Oct. 1991
JTECH Panel Report on Machine Translation in Japan	Jan. 1992
JTECH Panel Report on Database Use and Technology in Japan	April 1992
JTECH Panel Report on Bioprocess Engineering in Japan	May 1992
JTECH Panel Report on Flat Panel Display Technology in Japan	June 1992

The evaluations have revealed that in a significant number of technology-intensive industries, U.S. firms

- are losing, or have lost, their edge in research;
- continue to lose ground in the transition from research to product development/diffusion; and
- are losing still more ground in transition from product development to product implementation.

For example, a JTEC evaluation of factory automation showed that the United States was behind in development and product implementation of most of the technologies crucial to the industry. (See table 3.)

Table 3. Comparison of United States and Japan in development and implementation of factory automation technologies

	Research	Adv. Development	Product implementation
U.S. AHEAD	Software Vision	Software	Software
U.S. EVEN	Flexible mfg systems Non-vision Assembly Intelligent mechanisms Standards Manipulators Precision mechanism		Intelligent mechanisms Non-vision
U.S. BEHIND		Vision Manipulators Precision mechanism Intelligent mechanisms Assembly	Manipulators Flexible mfg systems Precision mechanism Assembly, vision

Source: Prepared by J. Morone from the JTECH Panel Report on Mechatronics in Japan.

In another recently released study on the construction industry, the JTEC panel reported that.

> Japanese construction companies have well-established, in house research and development programs, generously funded mainly from their own internal sources, and including well-equipped laboratories, on a level that is almost absent in U.S. construction companies. Partly through the application of their research findings, they have moved ahead of their U.S. counterparts in many areas.

Recent figures from the Construction Industry Institute (1988) indicate that U.S. construction companies have been losing their share of the global market; they show U.S. companies holding one-quarter of the worldwide major construction contracts in 1988, down from one-half in 1980.

A Federal study on the semiconductor industry described a similar situation. U.S. firms are lagging behind Japanese companies in the development of most semiconductor products. (See figure 12.) For example, in advanced processing of electronic materials, the experts found that "At present, the Japanese are ahead of the United States in the development and application of advanced process technologies. At least ten of the major semiconductor companies in Japan have vigorous programs targeted for projects with an expected payoff 7 to 10 years later. There are only a few, perhaps two, U.S. firms similarly involved" (NSF 1987).

The panel also found that the United States has lost the lead in more than three-fourths of the critical semiconductor technologies included in the study.[20]

As noted by the MIT Commission on Industrial Productivity study (Detouzos et al. 1989, p. 250):

> The loss of U.S. leadership across a wide range of semiconductor technologies in the short span of about a decade has enormous implications. Semiconductors are the basic building blocks for a rapidly expanding spectrum of high-growth, high-technology industries that touch every market sector: business, industry, consumer products, and defense. They are the most critical components for computers, telecommunications, factory automation and robotics, aerospace, radar, and many consumer products. They provide controls for still more products, including automobiles, appliances, machine tools, and military equipment.

The consumer electronics industry is probably the best example of a high-technology industry that has been almost completely annihilated by foreign competition. Data compiled by the Council on Competitiveness and presented in figure 13 show a dramatic contraction in U.S. consumer electronics companies' share of the domestic market.

Fortune magazine recently used a group of experts to put out a "scorecard" for 13 key industries. Five of these industries were given a grade of C or lower, with a C "connot[ing] vulnerability and the risk of continued decline, [and a] D mean[ing] a business is basically on its back."

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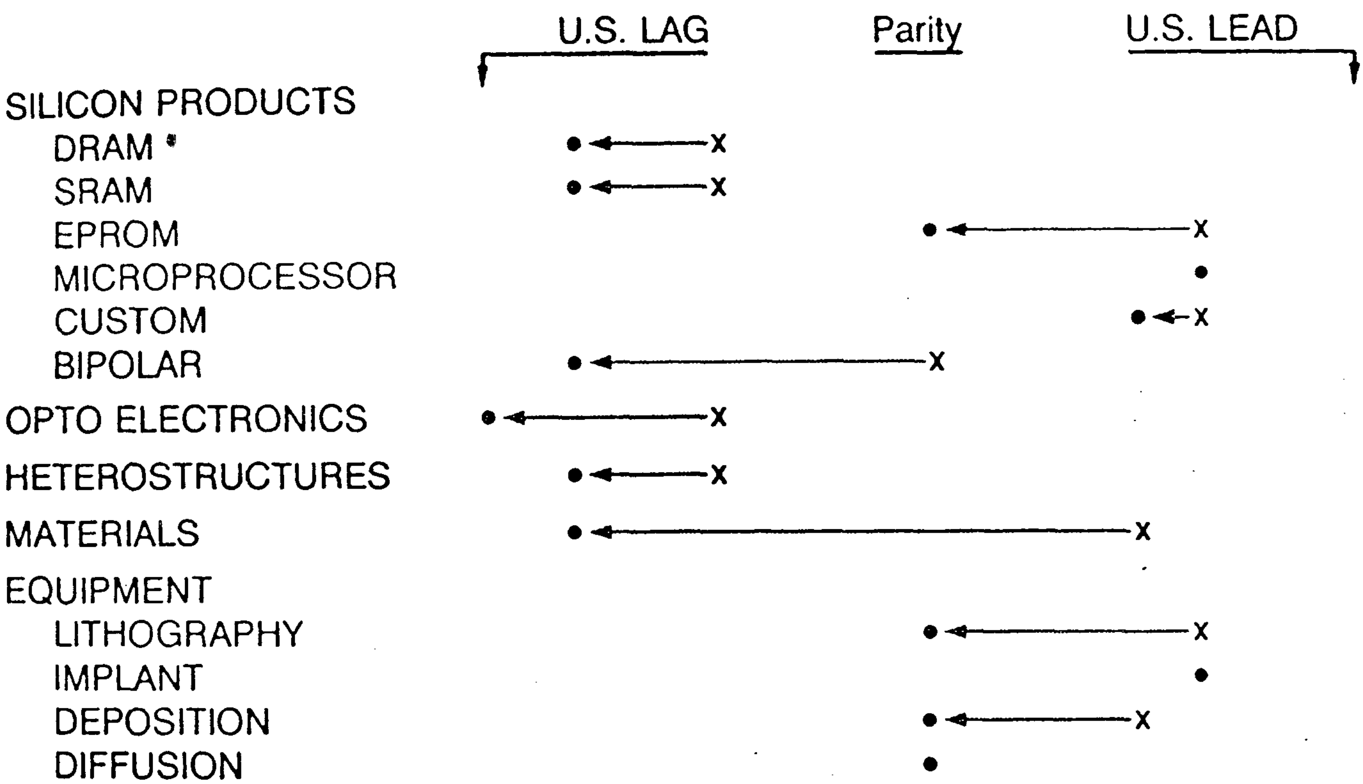
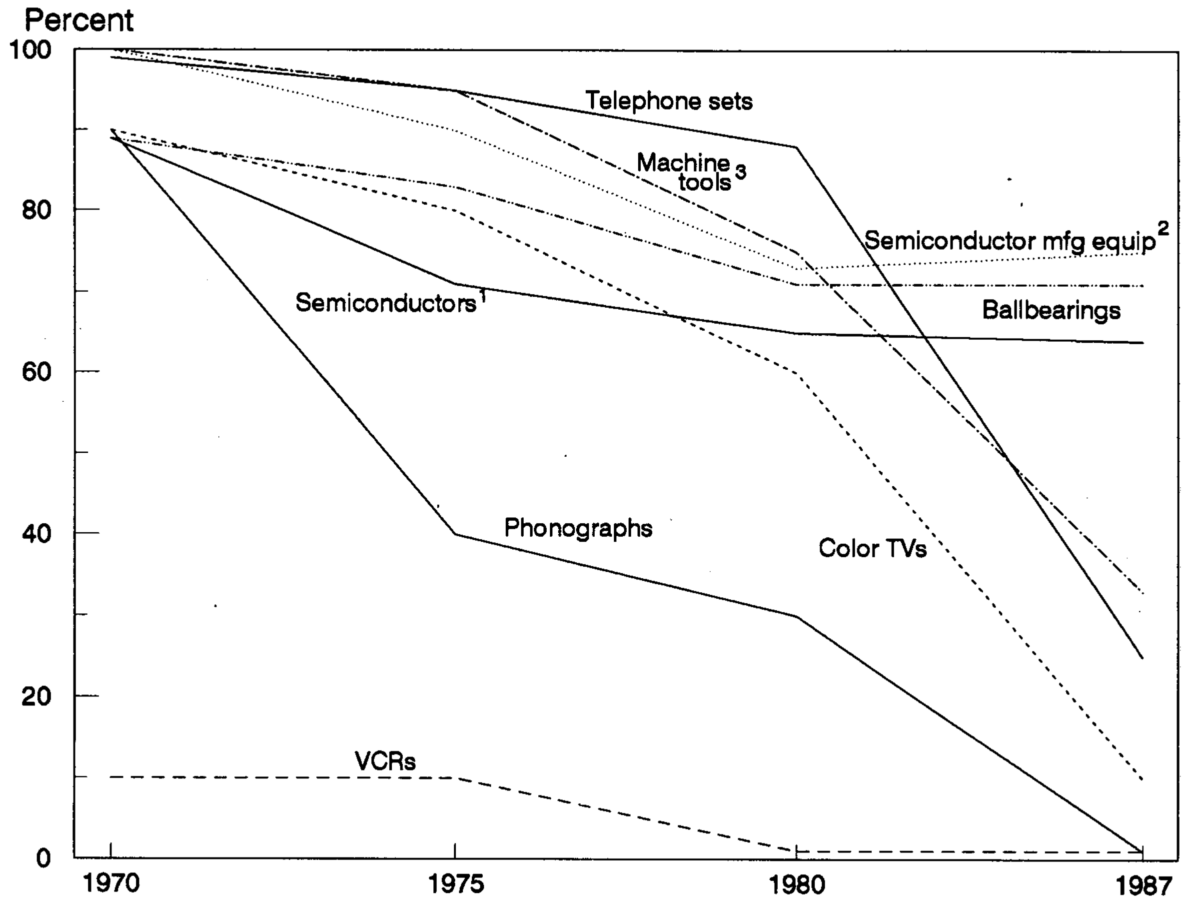
[20] See NSF (1987). For a national strategy that would benefit not only the semiconductor industry but also a broad set of industries that depend on technology for a competitive edge in the marketplace, see National Advisory Committee on Semiconductors (1992).

Figure 12. Between 1980 and 1987, the U.S. lost the lead to Japan in most semiconductor technologies



SOURCE: Federal Interagency Staff Working Group on the Semiconductor Industry

Figure 13. U.S. share of selected technology markets



The U.S. share of several technology markets eroded during the 1970s and 1980s

[1]Data are for semiconductor merchant companies only. U.S. company share includes production of foreign subsidiaries operating in the United States.

[2]Estimates only. No official data exist.

[3]Includes horizontal, numerically, controlled lathes and machining centers.

Source: Council on Competitiveness

The computer, industrial and farm equipment, motor vehicles, and metals industries all received grades in the C range; the electronics industry received a D (*Fortune* 1992).

Recently, three agencies of the U.S. Government (Commerce, Defense, and the Office of Science and Technology Policy [OSTP] in the White House), several private organizations (e.g., the Council on Competitiveness, the Aerospace Industries Association, and the Computer Systems Policy Project), the Japanese Ministry of International Trade and Industry, and the European Community all identified similar sets of critical technologies that currently, and will continue to, foster economic growth during the decade. Although Federal agencies, including NSF and Commerce, are supporting research programs that focus on most of these critical technologies, the amount of money going into these programs is small, and there is currently no systematic tracking of the levels of funding and the results of investment in each of the technologies. A limited amount of information has been prepared on an ad hoc basis to respond to congressional and other requests. For example, table 4 contains a few dollar figures for investment in critical technologies at NSF's Engineering Research Centers and Industry/University Cooperative Research Centers. Table 5 lists the first and second year awardees of Commerce's Advanced Technology Program.

Table 4. NSF support of critical technologies at Engineering Research Centers and Industry/University Cooperative Research Centers: 1992

Technology	Funding (in millions)
Materials	$12
Manufacturing	12
Information and communications technologies	20
Biotechnology and medical technology	6
Energy and the environment	5

Source: National Science Foundation, Directorate for Engineering

Table 5. 1991 and 1992 Advanced Technology Program awards

1991 Single Applicants (6)
Precision Optics for XRL, AT&T Bell Laboratories
Computer Interface—Cursive Handwriting Recognition, Communication Intelligence Corp.
Nonvolatile MRAM Semiconductors, Nonvolatile Electronics, Inc.
Tunable UV/VUV Solid State Laser, Light Age, Inc.
Machine Tool Compensation Techniques, Saginaw Machine Systems, Inc.
Thallium Superconductor Thin Film Processing, E.I. du Pont de Nemours & Co.
1991 Joint Ventures (5)
PWB Interconnect, National Center for Manufacturing Sciences
Holographic Mass Storage, Microelectronics and Computer Technology Corporation (MCC)
FPD Manufacturing, American Display Consortium
Solid State Laser—Point Source XRL, Hampshire, Inc. & McDonnell Douglas Electronic Systems Company
Short Wavelength Sources—Optical Recording, National Storage Industry Consortium
1992 Single Applicants (18)
Polymeric Switches for Optical Interconnects, IBM Corporation
Thermal Insulation Materials—Morphology Control and Processes for the Next Generation of Performance, Armstrong World Industries, Inc.
Autonomous Navigation in Quasi-Structured Environments, Transitions Research Corporation
Synthesis and Processing of Nanocrystalline Ceramics on a Commercial Scale, Nonphase Technologies Corporation
High Fidelity Digital Image Compression, Iterated Systems, Inc.
U.S. Self-Sufficiency in High-Quality Pyrethrin Production, AgriDyne Technologies, Inc.
Development of Cost-Effective Routes to Compatibilize Polymers in a Commingled Waste Stream, Michigan Molecular Institute
X-Ray and Neutron Focusing and Collimating Optics, X-Ray Optical Systems, Inc.
Low-Temperature Viral Inactivation, Bio-Eng, Inc.
Manufacturing Technology for High Performance Optoelectronic Devices Based on Liquid Phase Electro-Epitaxy, AstroPower, Inc.
High-Temperature Superconducting Racetrack Magnets for Electric Motor Applications, American Superconductor Corp.
A Three-Dimensional Database for Visualization of Human Physiology, Engineering Animation, Inc.

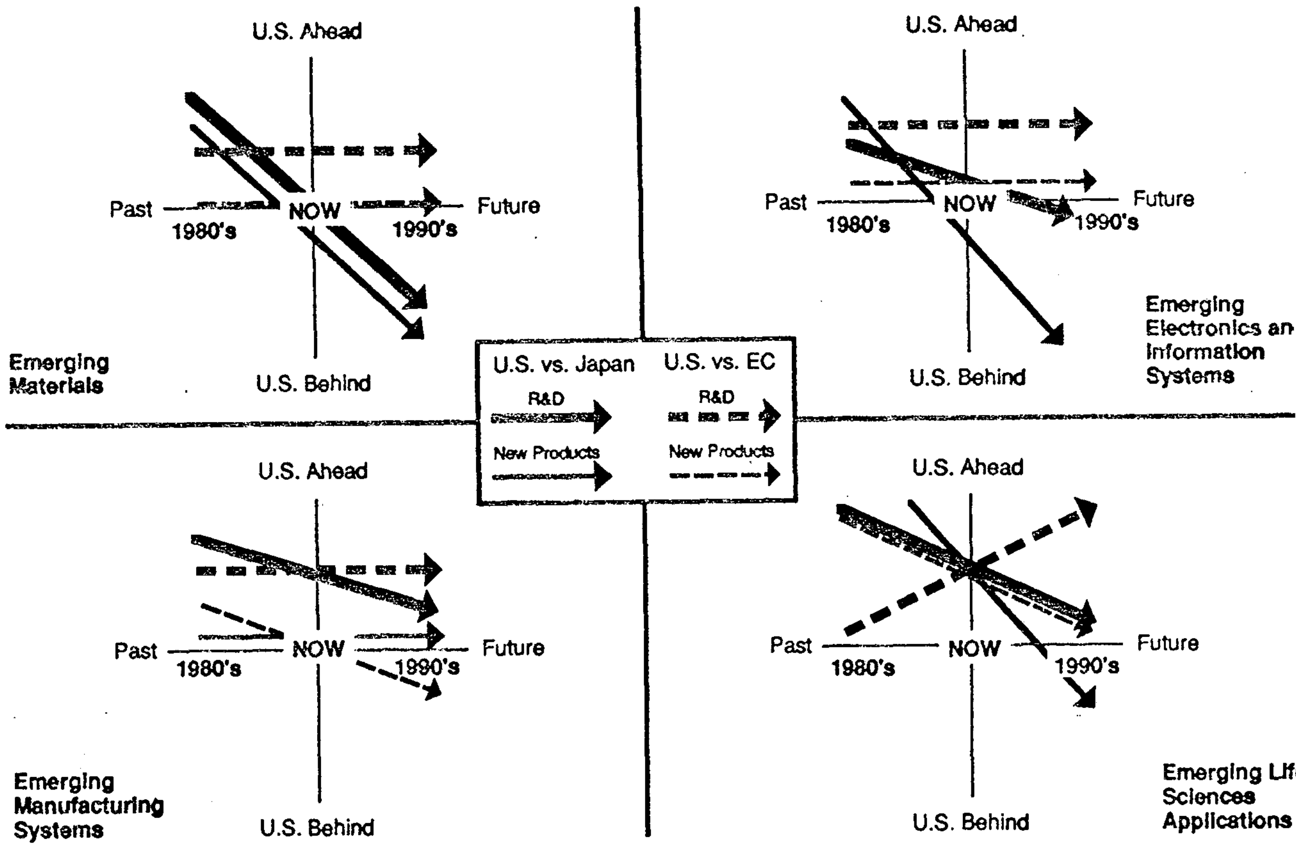
Table 5. 1991 and 1992 Advanced Technology Program awards
(Continued)

1992 Single Applicants (continued)
Novel Near-Net-Shape Processing of Engineered Ceramics, Garret Ceramic Components, a unit of Allied-Signal Aerospace
Development and Applications of Density Functional Software for Chemical and Biomolecular Modelings, Biosym Technologies, Inc.
Human Stem Cell and Hematopoietic Expansion Systems, Aastrom Biosciences, Inc.
Advancement of Monocrystalline Silicon Carbide Growth Processes, Cree Research, Inc.
Integrated Force Array, Center for Microelectronics at MCNC
A Feedback-Controlled Metalorganic Chemical Vapor Deposition Reactor, Spire Corporation
1992 Joint Ventures (9)
Ultra-High Density Magnetic Recording Heads, National Storage Industry Consortium
Neural Network Control and Sensors for Complex Materials, Honeywell/Hercules Aerospace/Sheldahl/3M
NCMS Rapid Response Manufacturing, National Center for Manufacturing Sciences
Hybrid Superconducting Digital System, Conductus, Inc./TRW Inc./Hewlett-Packard/Stanford U./U.C. Berkeley
Monolithic Multiwavelength Laser Diode Array Spanning 430 to 1100 nm, Spectra Diode Laboratories, Inc./Xerox Corp.
Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing, Auto Body Consortium
Cyclic Thermoplastic Liquid Composite Molding for Automotive Structures, Ford Motor Co./General Electric
Scalable High-Density Electronics Based on MultiFilm Modules, The American Scaled-Electronics Consortium
PREAMP—Pre-Competitive Advances Manufacturing of Electrical Products, South Carolina Research Authority

Source: U.S. Department of Commerce, NIST

The Commerce Department (1990) issued a report containing a diagram and some "report cards" that depict where the United States stands, vis-à-vis Japan and the European Community, in the research and exploitation of emerging technologies. Figure 14 and tables 6 and 7 are taken from this report. The outlook these experts predict is not particularly favorable for U.S. competitiveness. For example, table 7 shows the United States falling behind Japan in all but 3 of the 13 critical technologies addressed in the report. The authors concluded that, "If current trends continue . . . before the year 2000, the United States could lag behind Japan in most emerging technologies and trail the European Community in several of them."

Figure 14. A Commerce Department evaluation revealed an erosion in U.S. technology leadership



SOURCE: U.S. Department of Commerce, Technology Administration

Table 6. Relative performance of the United States in several critical technologies

	Versus Japan	Versus Europe
Behind	Advanced materials Advanced semiconductor devices Digital imaging technology High-density data storage Optoelectronics	Digital imaging technology
Even	Superconductors	Flexible computer-integrated mfg Semiconductors
Ahead	Artificial intelligence Biotechnology Flexible computer-integrated mfg High-performance computing Medical devices and diagnostics Sensor technology	Advanced materials Advanced semiconductor devices Artificial intelligence Biotechnology High-density data storage High-performance computing Medical devices and diagnostics Optoelectronics Sensor technology

Source: U.S. Department of Commerce, Technology Administration

Table 7. Future trends for United States in several critical technologies

	Versus Japan	Versus Europe
Losing Badly	Advanced materials Biotechnology Digital technology Superconductors	Digital imaging technology Flexible computer-integrated mfg
Losing	Advanced semiconductor devices High-density data storage High-performance computing Medical devices and diagnostics Optoelectronics Sensor technology	Medical devices and diagnostics
Holding	Artificial intelligence Flexible computer-integrated mfg	Advanced materials Advanced semiconductor devices High-density data storage Optoelectronics Sensor technology Superconductors
Gaining		Artificial intelligence Biotechnology High-performance computing

Source: U.S. Department of Commerce, Technology Administration

The National Critical Technologies Panel (1991), sponsored by OSTP, issued a report on the results of its work. In this document, the panel identified and defined 22 critical technologies, gave the reasons each was selected, evaluated their status in the United States vis-à-vis other countries, and reported on international trends. Table 8 shows a list prepared by the panel comparing its 22 critical technologies with those identified by the Departments of Commerce and Defense.

Table 8. Comparison of national critical technologies with Department of Commerce emerging technologies and Department of Defense critical technologies

National critical technologies	Commerce emerging technologies	Defense critical technologies
	Materials	
Materials synthesis and processing	Advanced materials	Composite materials
Electronic and photonic materials	Advanced semiconductor devices	Semiconductor materials & microelectronic circuits
	Superconductors	Superconductors
Ceramics		
Composites	Advanced materials	Composite materials
High-performance metals and alloys		
	Manufacturing	
Flexible computer integrated mfg	Flexible computer integrated mfg	
Intelligent processing equipment	Artificial intelligence	Machine intelligence and robotics
Micro- and nanofabrication		
Systems management technologies		
	Information and communications	
Software	High-performance computing	Software producibility
Micro- and optoelectronics	Advanced semiconductor devices	Semiconductor materials and microelectronic circuits
	Optoelectronics	Photonics
High-perf. computing & networking	High-performance computing	Parallel computer architecture
High-definition imaging & displays	Digital imaging	Data fusion
Sensors and signal processing	Sensor technology	Data fusion
		Signal processing
		Passive sensors
		Sensitive radars
		Machine intelligence and robotics
Data storage and peripherals	High-density data storage	Photonics
Computer simulation & modeling	High-performance computing	Simulation and modeling
		Computational fluid dynamics
	Biotechnology and life sciences	
Applied molecular biology	Biotechnology	Biotech materials and processes
Medical technology	Medical device and diagnostics	

Table 8. Comparison of national critical technologies with Department of Commerce emerging technologies and Department of Defense critical technologies
(continued)

Aeronautics and surface transportation		
Aeronautics Surface transportation technologies		Air-breathing propulsion
Energy and environment		
Energy technologies Pollution minimization, remediation, and waste management		
		No national critical technologies counterpart: high-energy density materials, hypervelocity projectiles, pulsed power, signature control, weapon system environment

Note: National critical technologies were designated by the National Critical Technologies Panel; emerging technologies were designated by the Department of Commerce; defense critical technologies were designated by the Department of Defense.

Source: *Report of the National Critical Technologies Panel*, Office of Science and Technology Policy, March 1991

The recently released Council on Competitiveness (1991) report contains

- a list of critical generic technologies and assessments of the U.S. competitive position in each technology;[21]
- a comparison of critical technologies lists prepared by the Department of Defense, the Department of Commerce, the Japanese Ministry of International Trade and Industry, and the European community; and
- recommendations for government, academia, and industry.

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[21]The Council has also published "competitive profiles" providing detailed evaluations of the competitive strengths and weaknesses of nine industries: aerospace, chemical and allied products, computers and software, construction, drugs and pharmaceuticals, electronic components and equipment, machine tools, motor vehicles, and telecommunications.

The Council's categorization of technologies in which the United States is either strong, competitive, weak, or losing (or has lost) is shown in table 9. The authors emphasize that even in technologies where the United States is strong or competitive, its position has been eroding, and there are no technologies in which the United States is gaining on its competitors. According to the Council, "Many of the areas where the United States is weak reflect the effects of high capital costs; the lack of cooperative relations between equipment, materials and components suppliers and their customers; and an underemphasis on manufacturing" (Council on Competitiveness 1991, p. 33).

These various panels comprised of government and nongovernment experts assembled to evaluate the status of the United States, vis-à-vis other countries, in technology advancement and application agreed that the preeminent technology leadership position enjoyed by the United States for decades has been eroding. To identify the factors adversely affecting U.S. industry's ability to compete in global markets for high-tech products, the Committee requested the assistance of the Industrial Research Institute[22] to secure input from leading industrial R&D officials.

Potential Causes for the Erosion in U.S. Technology Leadership

Based on its own discussions and review of external contributions, the Committee was able to identify five major categories and 6 to 10 factors under each of the five categories that may be responsible for the erosion in U.S. technology leadership. The list prepared by the Committee was used by IRI to conduct a survey of its membership to gauge how industry officials perceive and rate the categories and factors. IRI agreed to share the results with the Committee. The five major categories were

- general management practices,
- external financial pressures,
- changing global technological environment,
- technology management practices, and
- Federal technology policy.

The survey was mailed to the 237 members of IRI with U.S. mailing addresses. Completed questionnaires were received from 139 members. Survey recipients were asked to rank both the five categories and the factors under each of the categories from highest to lowest in

[22] IRI is an association of more than 250 companies. Its major function is to coordinate the study of problems confronting managers of industrial research and development. A company may join IRI if it (1) maintains a technical staff and research laboratory in the United States, and (2) engages primarily in industrial production. The IRI membership includes R&D directors from most large U.S. R&D-performing companies. IRI member companies account for approximately 85 percent of industry-funded R&D in the United States.

Table 9. Council on Competitiveness' assessment of the U.S. competitive position in critical technologies

TECHNOLOGIES IN WHICH THE UNITED STATES IS STRONG

Materials and Associated Processing Technologies
- Bioactive/Biocompatible Materials
- Bioprocessing
- Drug Discovery Techniques
- Emissions Reduction
- Genetic Engineering
- Recycling/Waste Processing

Engineering and Production Technologies
- Computer-Aided Engineering
- Systems Engineering

Electronic Components
- Magnetic Information Storage
- Microprocessors

Information Technologies
- Animation and Full Motion Video
- Applications Software
- Artificial Intelligence
- Computer Modeling and Simulation
- Data Representation
- Data Retrieval and Update
- Expert Systems
- Graphics Hardware and Software
- Handwriting and Speech Recognition
- High-Level Software Languages
- Natural Language
- Neural Networks
- Operating Systems
- Optical Character Recognition
- Processor Architecture
- Semantic Modeling and Interpretation
- Software Engineering
- Transmitters and Receivers

Powertrain and Propulsion
- Airbreathing Propulsion
- Low Emission Engines
- Rocket Propulsion

TECHNOLOGIES IN WHICH THE UNITED STATES IS COMPETITIVE

Materials and Associated Processing Technologies
- Catalysts
- Chemical Synthesis
- Magnetic Materials
- Metal Matrix Composites
- Net Shape Forming
- Optical Materials
- Photoresists
- Polymers
- Polymer Matrix Composites
- Process Controls
- Superconductors

Engineering and Production Technologies
- Advanced Welding
- Computer Integrated Manufacturing
- Human Factors Engineering
- Joining and Fastening Technologies
- Measurement Techniques
- Structural Dynamics

Electronic Components
- Logic Chips
- Sensors
- Submicron Technology

Information Technologies
- Broadband Switching
- Digital Infrastructure
- Digital Signal Processing
- Fiber Optic Systems
- Hardware Integration
- Multiplexing
- Spectrum Technologies

Powertrain and Propulsion
- Alternative Fuel Engines
- Electrical Storage Technologies
- Electric Motors and Drives

TECHNOLOGIES IN WHICH THE UNITED STATES IS WEAK

Materials and Associated Processing Technologies
- Advanced Metals
- Membranes
- Precision Coating

Engineering and Production Technologies
- Design for Manufacturing
- Design of Manufacturing Processes
- Flexible Manufacturing
- High-Speed Machining
- Integration of Research, Design and Manufacturing
- Leading-Edge Scientific Instruments
- Precision Bearings
- Precision Machining and Forming
- Total Quality Management

Electronic Components
- Actuators
- Electro Photography
- Electrostatics
- Laser Devices
- Photonics

Powertrain and Propulsion
- High Fuel Economy/Power Density Engines

TECHNOLOGIES IN WHICH THE UNITED STATES IS LOSING BADLY OR HAS LOST

Materials and Associated Processing Technologies
- Display Materials
- Electronic Ceramics
- Electronic Packaging Materials
- Gallium Arsenide
- Silicon
- Structural Ceramics

Engineering and Production Technologies
- Integrated Circuit Fabrication and Test Equipment
- Robotics and Automated Equipment

Electronic Components
- Electroluminescent Displays
- Liquid Crystal Displays
- Memory Chips
- Multichip Packaging Systems
- Optical Information Storage
- Plasma and Vacuum Fluorescent Displays
- Printed Circuit Board Technology

SOURCE: Council on Competitiveness, *Gaining New Ground: Technology Priorities for America's Future*, pp. 31-34.

importance.[23] In addition, they were provided space to add other factors they felt were important but may have been omitted from the Committee's list. They were also asked to provide recommendations for addressing the problems responsible for the erosion in U.S. technology leadership and to identify their companies' major industry (or industries) and domestic employment size group.

According to the industrial R&D officials who participated in the survey, *general management practices* and *external financial pressures* are more at fault for the erosion in U.S. technology leadership than are the other three categories. *Federal technology policy* was ranked last (closely behind *technology management practices*). Although *Federal technology policy* was ranked below the other categories, it cannot be inferred that the R&D directors consider it to be unimportant in contributing to the decline in U.S. technology leadership, only less important than the other four categories.

Nevertheless, it would appear that there is a strong consensus among industrial R&D officials that *general management practices* and *external financial pressures* are more to blame for the erosion in U.S. technology leadership than *Federal technology policy*. This finding, however, does not lead to the conclusion that increasing Federal support of technology development or other new Federal policies and programs would be ineffectual in strengthening U.S. industrial competitiveness. The issue is far too complex and multifaceted to downplay the role of any sector. As stated in the recent Council on Competitiveness (1991, p. 44) report, "Each sector has a responsibility. Government must work with the private sector to make the development and application of technology a new national priority. Industry must improve its ability to commercialize technology. And universities must make sure that their research and education programs adequately address the technology needs of industry."

It is also important to emphasize that the survey results reflect the views of a single set of industry representatives. Although this group of leading R&D officials is a particularly relevant and appropriate group for this study, their opinions may not represent the composite views of other industry leaders. For example, the rankings might have been quite different had the respondents been CEOs, chief financial officers, or manufacturing leaders. Also, with respect to the role of Federal technology policy, many CEOs of major high-technology companies have voiced their support for a larger role for the Federal Government in fostering industrial competitiveness; their views are reflected in reports such as *Gaining New Ground: Technology Priorities for America's Future* (Council on Competitiveness 1991).

The industry R&D officials' ranking of the five categories, however, is consistent with the observations of leading experts. For example, Rosenbloom and Abernathy (1982) contend that *general management practices* are at least partially to blame for some of the difficulties U.S. consumer electronics companies encountered in competing successfully with their foreign

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[23]Not all respondents ranked every category; some did not rank all factors within a category; and a few gave identical rankings to some of the factors. Missing and duplicative rankings were imputed using statistical procedures designed to maximize respondents' ordinal placement of categories and factors and minimize bias.

counterparts. It should be acknowledged, of course (and several IRI officials noted this) that the two categories of *general management practices* and *external financial pressures* are closely linked: external financial pressures constrict, to a great extent, general management decision-making.

Under the category *general management practices,* survey respondents placed greatest emphasis on "short time horizons" and "management by the numbers rather than by strategic vision." "Failure and/or inability to integrate technology into business strategy" and "corporate executives' lack of scientific and technical insight and lack of experience in the management of science and technology" were also frequently mentioned. A common theme of numerous studies is that "U.S. firms [are] less willing than their rivals to live through a period of heavy investment and meager returns in order to secure a foothold in a growing market" (Detouzos et al. 1989, p. 53). For example, "The short-term orientation of U.S. firms and their unwillingness to commit resources to the development and commercialization of new technologies is a critical factor in explaining the failure of U.S. firms to compete in the fast changing electronics industry" (Sanderson 1989, p. 44). Japanese companies' success in developing and manufacturing a videocassette recorder for the consumer market is frequently cited as an example of how perseverance eventually paid off. In contrast, U.S. companies failed to capitalize (on what was initially a U.S. invention) because they were unwilling to make the long-term commitment of resources necessary to perfect a product for the consumer market.[24] The need for financial incentives that would induce management to adopt a longer term perspective was mentioned by one-third of those IRI members who added recommendations to their questionnaires.

Survey respondents overwhelmingly selected "growing dominance of institutional investors in equity markets and their demand for short-term returns on their investments" as the most important factor in the category, *external financial pressures.* "High cost of capital" finished a distant second in the ranking of factors under this category.

Although it is widely assumed, and several studies have suggested, that Japanese companies' greater propensity to invest in long-term R&D, process technology, and capital equipment can be attributed to a lower cost of capital, the issue—whether there is truly a significant difference in the cost of capital between the United States and Japan—is still being debated. In addition, there is disagreement over how much this difference, if it exists, is responsible for the longer time horizons of Japanese companies compared to those of U.S. firms. In a recent study conducted for the National Academy of Engineering's Committee on Time Horizons and Technology Investment, Joseph Morone and A.S. Paulson (1991) assert that "While there is heated dispute about whether or not the cost of capital in the United States is higher than it is in Japan, there is a growing consensus that Japanese firms behave *as if* their cost of capital is lower."

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[24] A clarification is needed at this point. The Committee is not here advocating more investment in long-term research. Rather, the point being made is that because of their short time horizons, companies are more willing to spend their earnings on, for example, paying out large dividends or acquiring other companies, rather than on developing and, more importantly, applying technology to perfect and create new products and processes. Indeed, long-term research is not the issue in the U.S. electronics industry; what is lacking is perseverance, the patience needed to tinker with available technology, and speed of commercialization.

Their interviews with 15 corporate executives revealed widely differing opinions on whether the cost of capital is having a significant impact on U.S. competitiveness. Officials who felt that the cost of capital was having a minimal effect on their firms' ability to compete tended to represent companies in better financial condition and at the forefront of technology leadership in their respective industries than those who contended that the cost of capital was a major handicap, limiting their companies' ability to take on more risky investments in capital equipment and R&D.

There was less consensus in the IRI members' ranking of factors under *global technological environment* than was displayed in their ordering of the factors under *general management practices* and *external financial pressures*. "Growing difficulty of controlling enough technological competitive advantage to sustain an entry barrier" was ranked highest, marginally ahead of the factor ranked second, "declining lead times and faster product turnover cycles." These two factors received almost the same number of first and second place rankings and are closely related. Both are prominent characteristics of the electronics industry where rapid advancements in technology are continuously shortening product and process cycles, thus increasing the risk that companies will be unable to fully recover their investments and make a profit before their products become obsolete.

Several of the experts invited to discuss their recent research with the Committee spoke about the contrast between U.S. free market policies and the protectionist policies of competitor nations and emphasized the negative effect that this difference was having on U.S. companies' ability to compete in global markets. For example, Candace Howes (forthcoming) stressed that Japan's export-based development strategy, a key component of which is the export of motor vehicles, precludes U.S. automobile manufacturers from competing on a "level playing field."

In a recent article, Edward Steinmueller (1988) described how the Japanese Government's policies were successful in protecting the domestic computer industry.

> A major factor in the rapid growth of Japanese computer manufacture has been the support of the Japanese government for this industry . . . The prohibition of direct investment may have been the most effective means of isolating the Japanese market from the competitive influences prevailing in international markets. This prohibition prevented U.S. and European companies from setting up the coordinated manufacturing, distribution, and support systems in Japan that have been shown to be important to competitive success in the international computer industry.

"Relative slowness in product development and commercialization" was ranked first in the *technology management practices* category and "reluctance to invest in new enabling technologies because the R&D may be too expensive, long-term, multi-industry, and interdisciplinary" was ranked second, although it received the highest number of first place rankings.

A standard conclusion of recent studies on competitiveness is that U.S. companies trail their foreign rivals in the commercialization of new technologies. They fall short of their foreign competitors by being slow to digest and respond to market information and by missing crucial opportunities to be first on the market with low-cost, high-quality products. As stated in a

Council on Competitiveness report (1988, pp. 1, 9), "The speed with which firms are able to translate innovations into commercial products and processes often spells the difference between success and failure . . . By rapidly translating new technology into new products and processes, firms in other countries have gained access to new markets and reaped considerable commercial rewards."

In many U.S. industries, development of new products proceeds at a much slower pace than in other countries. For example, a study of the automobile industry revealed that Japanese companies required on average only half the number of engineering hours and two-thirds the time of U.S. companies to transform a concept into a product ready for the sales floor (Clark and Fujimoto 1986). The need for more rapid commercialization of new technology was cited by ten of the IRI officials in their recommendations.

The need for speedy conversion of ideas into products requires firms to have access to an ever-expanding, relevant engineering knowledge base and the techniques of translating that base quickly into practice. Two of the primary reasons U.S. companies are relatively slow in translating innovation to products and processes are (1) the lack of a sufficiently broad and deep fundamental engineering research base, and (2) inadequate fundamental engineering research. In addition, "reluctance to invest in new enabling technologies . . ." is linked to underinvestment by industry in engineering research.[25] The level of Federal support for basic engineering research actually declined in constant dollars from 1989 to 1991 and the Federal support for applied engineering research declined gradually over the decade (see NSB 1991, figure 4-6, p. 97).

Two-thirds of the respondents gave first or second place rankings to "lack of long-term strategies for expanding the economy (and tax revenues) through technological competitiveness" under the *Federal technology policy* category. The importance attributed to this factor can be interpreted as a statement (from most respondents) in favor of a comprehensive national technology strategy aimed at improving industrial competitiveness. Twenty-five of the IRI members mentioned the need for such a strategy in their recommendations. The two factors that refer to education, "too little attention to the training of future scientists and engineers" and "too little attention to pre-college education," were ranked second and fourth, respectively. The need to strengthen the U.S. educational system was mentioned more frequently than any other in respondents' recommendations.

The results of the IRI survey are discussed in greater detail in appendix B.

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[25]These concerns were addressed in detail in NRC (1987).

Part II
Recommendations

Introduction

The Committee related its recommendations to its four major findings. The recommendations focus on areas in which the Federal Government, and especially the National Science Foundation (NSF), may be able to contribute to strengthening U.S. industrial competitiveness. Although NSF can play a key innovative role—and one in which its skills in building partnerships can be particularly used—its support of relevant research is but a small fraction of the total R&D industrial enterprise. The most important contribution NSF can make, in fact, is to continue to concentrate on what it does best and for which it is especially qualified—the support of basic research and education. Investment in these two areas is critical to successfully maintaining U.S. technological leadership, even though, unlike other Federal programs and policies aimed at bolstering U.S. competitiveness, the benefits may not be visible for several years.

In addition to making general recommendations, the Committee also made several specific recommendations—some directed to individual Federal agencies, others to the government in general. Both the general recommendations and those specific ones not directly related to NSF are listed below under each of the four findings. Following these general and specific recommendations, NSF programs and policies are discussed, with particular emphasis on those that now affect—or have the potential to affect—industrial competitiveness; specific recommendations to the Foundation are also included in this discussion.

General Recommendations

1. ***The real rate of growth in U.S. industrial R&D spending has declined since the late 1970s and early 1980s. In addition, there has been a deterioration in the U.S. position relative to that of its major international competitors, whose investment in nondefense R&D has been growing at a much faster pace than U.S. nondefense R&D since the mid-1980s.***

General Recommendation: Although industry must take the lead in the resumption of more rapid growth of industrial R&D to match that of U.S. competitors, the Federal Government has a direct, crucial role in establishing a healthy economic environment conducive to R&D investment. Monetary, fiscal, and regulatory policies are important determinants of the climate for investment, and therefore can enhance or impede U.S. industry's ability to compete successfully in the global marketplace. Presidential and congressional action should include adoption of fiscal and monetary policies that encourage strategic investment in both tangible (e.g., plant and equipment) and intangible (e.g., training) assets for R&D and changes in Federal regulations and the regulatory process to promote and facilitate technological innovation.

Organizations such as the Council on Competitiveness and the Competitiveness Policy Council have issued recommendations addressing these factors. Although the Committee has nothing significant to add to their lists, it strongly endorses such recommendations, including urging the President and Congress to do the following (Council on Competitiveness 1991, p. 4).

> Make the cost of capital . . . competitive with that of America's major competitors by accelerating depreciation schedules for manufacturing equipment, making the R&D tax credit permanent and broadening it to include manufacturing engineering and process R&D, and placing a permanent moratorium on Treasury Regulation 1.861-8, which creates a tax benefit for U.S. corporations that move their R&D facilities to a foreign country [and] promote capital formation, antitrust reforms, regulatory guidelines, export policies and foreign market-opening measures that are conducive to U.S. manufacturing, investment in technology and quality of life.

2. ***The allocation of U.S. R&D expenditures is not optimal.***

- ***The balance between defense and nondefense expenditures is disadvantageous compared to that of foreign competitors.***
- ***Too little is spent on process-oriented rather than product-oriented R&D.***
- ***Inadequate effort is devoted to fundamental engineering research.***
- ***There is insufficient emphasis on emerging and precompetitive technologies.***
- ***The United States faces an emerging risk of losing its traditional strength in pioneering discoveries and inventions.***

General Recommendation: Federal support of R&D directly relevant to industrial competitiveness should be increased. The primary need is to reorient Federal R&D budgets away from noncivilian government missions and toward the needs of industry. More programs should be created that encourage the interaction of scientists and engineers in universities and industry in exploring joint research interests that hold the promise of pioneering discoveries and inventions. In addition, traditional and nontraditional education programs that motivate creativity, innovation, and entrepreneurship should be supported.

The Committee is not alone in making this type of recommendation. Others have noted, for example, that "when it comes to technology, U.S. public policy can no longer afford to be preoccupied with basic research and military issues; economic security and industrial competitiveness are also vital considerations" (Inman and Burton 1991). The recent reports on the deteriorating position of the U.S. industrial sector vis-à-vis other countries emphasize the need to elevate technological competitiveness to an equal footing and integrate it with other national priorities such as improving the state of the economy, national security, and health care.

An appropriate first step would be for the President and Congress to implement the national technology policy that was set forth by the President's Office of Science and Technology Policy (OSTP) in a document entitled *U.S. Technology Policy*. A key component of the OSTP statement is the advocacy of Federal participation "with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications" (OSTP 1990). Several Federal programs that contribute to this goal—e.g., NSF's Engineering Research Centers and Commerce's Advanced Technology Program and Manufacturing Technology Centers—have already been established. The Committee believes, however, that more needs to be done by strengthening and fine-tuning these and other ongoing activities and by creating selected new programs.

U.S. industry's relative slowness in product development and commercialization is clearly a related issue in the debate on competitiveness. The Japanese Technology Evaluation Center and critical technologies assessments and the results of the Industrial Research Institute (IRI) survey, all of which were discussed in part I of this report, document the magnitude and seriousness of the problem. Many IRI members and other corporate leaders, as well as government legislators and policymakers, advocate increased Federal support of programs and policies designed to promote the rapid commercialization of technology. Their agenda includes the provision of incentives and assistance to companies to

- integrate their approach to research, design, manufacturing, and maintenance;
- maximize the use of concurrent engineering, total quality management, just-in-time production, and other modern techniques;
- invest in more process and manufacturing R&D; and
- identify and acquire technology from outside sources.

A related issue, and one that the Committee believes to be a pervasive problem in the United States today (although a lack of systematic data has precluded detailed discussion of this topic to this point) is the insufficient attention given to fundamental engineering research in industry, government, and universities. Every firm must have an ever-expanding, relevant engineering knowledge base—and the hardware and software techniques for translating that base quickly into practice—in order to convert ideas into products rapidly and efficiently. The often-cited lack of emphasis on process improvement and manufacturing, along with excessive time delays from concept to available product, attest to a pervasive lack of understanding of, appreciation for, and sufficient attention to the vital role of fundamental engineering research by U.S. industry, government, and universities. Yet there is no sufficiently broad and deep fundamental engineering research base on which to build; furthermore, there are an inadequate number of engineering researchers in U.S. industry who are equipped to, and called upon to, extend that base as needed. The greater the storehouse of fundamental engineering research, and the greater the ability in industry and government to extend it as needed for proprietary or national reasons, the better able the qualified engineer is to innovate in an integrated system of design, manufacture, and maintenance.

The Committee makes the following recommendations:

- Several fledgling programs within the Department of Commerce's National Institute of Standards and Technology (NIST)—including the Advanced Technology Program, the Manufacturing Technology Centers Program, and the State Technology Extension Program—should be expanded. In addition, the strong NIST budget proposal by the Administration, which calls for doubling the agency's budget by 1996, should be supported. Such an increase is needed to "allow NIST to conduct research and provide laboratory support for manufacturing technologies, information technologies, and other emerging technologies that are extremely important to the U.S. economy" (U.S. Congress 1991).

- Federal agencies, where appropriate, should incorporate the following elements as either primary or secondary criteria in evaluations for awarding R&D support: (1) relevance to the critical technologies in which the U.S. lead is slipping, and (2) relevance to U.S. industrial competitiveness.

- New programs should be established that stimulate the redirection of government resources from defense to nondefense R&D.

- Activities that directly support technology transfer activities in Federal laboratories should be expanded.

3. ***U.S. expenditures are not as effective as they should be in producing needed results.***

    - ***The U.S. competitive position in important, technologically based industries is deteriorating.***

    - ***The U.S. time horizon has become too short, and the Nation's business decisions tend not to be based on strategic technological considerations.***

    - ***U.S. R&D is not translated into beneficial economic and social results quickly enough.***

General Recommendation: Traditionally, Federal R&D agencies have played no role with respect to factors that influence the managerial context for technology. This report suggests that the business context for technology is such an important determinant of the strength of U.S. industrial technology that it may be time to reexamine this traditional isolation from business issues. The Committee also believes that support should be increased for science and engineering research and education programs that emphasize production systems engineering and the integration of product design and manufacturing. Activities should also be encouraged that lead to faster dissemination of research results among researchers in academia, industry, and other sectors.

Some U.S. companies have managed to succeed in the high-technology arena despite inherent disadvantages. These companies have made the adjustments necessary to thrive within the prevailing financial investment climate. Operating under the same financial pressures as other companies to produce quick profits to satisfy impatient stockholders, their leaders continue to have long-range vision and to support risky projects in which returns may not be realized for a relatively long time.

Why are some U.S. firms successful in the global marketplace, when others have not been? According to Morone and others, these firms share a "style of general managerial decision making that is driven by strategic imperatives . . . rather than by financial objectives"[1] (Morone forthcoming). There is now a considerable body of evidence (including the IRI survey results) suggesting that general management bears much of the responsibility for the United States' lackluster performance in high-technology markets. More research is needed to determine how some companies have mitigated the constraints imposed by external financial pressures.

4. ***The current information base on industrial science and technology is inadequate. The current knowledge base has gaps, is questionable in parts, and often does not provide enough detail to meet the needs of policymakers.***

General Recommendation: Although policymakers could use more informative, integrated, and better quality, data on industrial technology and the role of R&D investment in economic activity than are currently available, the feasibility and/or the costs of collecting such data are frequently not known. The Committee recommends that a systematic assessment be carried out that examines the feasibility and cost of developing and tracking a set of industrial science and technology indicators that would be of value to policymakers concerned with technology policy, U.S. industry's involvement in high-technology markets, and R&D investment in emerging technologies.

In the course of its investigation, the Committee discovered gaps in the government's databases, including a lack of, or incomplete, information on

- international comparisons of industrial R&D performance;
- R&D investment in narrowly defined product areas and emerging technologies;
- comparisons of the content and allocation of R&D resources;
- the R&D performance and achievements of nonprofit organizations, including R&D consortia;

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[1]Dr. Morone's list of "strategic imperatives" includes "striving to be first to market, with the best performing products, at the lowest costs, and with the highest quality, in every market segment and price tier, in every region of the globe."

- R&D contracted to or sourced from outside organizations;
- foreign companies' R&D investment in the United States;
- independent research and development; and
- R&D performed in the service sector.

The Committee recognizes that it may not be possible or feasible to collect data in all of the areas noted above. For example, companies may be unwilling, or perhaps unable, to compile and provide more disaggregated data; nonresponse to NSF (and other) surveys has been a major problem for many years. Also, collection of data on some topics of interest, including emerging technologies, is likely to prove especially difficult because survey respondents sometimes use varying definitions when supplying the requested data (even though NSF provides detailed instructions and definitions along with its questionnaires).

NSF Recommendations

What NSF Is Currently Doing

NSF contributes in many ways to U.S. scientific and technological leadership. It contributes through its science and engineering basic research and education programs and through programs specifically focused on industry competitiveness. Fundamental research in science and engineering has made important contributions to the competitive strength of U.S. industry. In recent months, there has been a major effort throughout the Foundation to enhance industrial participation in NSF programs.[2] One of the principal outcomes of this outreach effort should be an increase in the amount of NSF-supported research providing a foundation for the most important and immediate industrial needs.

Many NSF programs and projects have high rates of industry involvement:

- The **Industry/University Cooperative Research Centers Program** provides "seed" support for more than 50 centers to work in collaboration with industry on research relevant to industrial needs.

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[2]NSF is already demonstrating serious commitment in addressing the question of how it can increase interaction between academia and industry to speed the deployment of new knowledge and technologies to industry. The NSF Director recently established an internal NSF Committee—the Industrial Programs Coordinating Committee—to (1) coordinate programs that focus on industrial collaboration; (2) provide recommendations for a substantive long-term program of activities to strengthen NSF's interactions with industry and the latter's interactions with academia; (3) develop a brochure focused on industry, especially smaller firms, depicting the benefits of industry-university collaboration; and (4) develop a strategy for improved outreach to industrial organizations.

- The **Engineering Research Centers Program** is designed to focus cross-disciplinary teams on research and education on engineering systems important for competitiveness.

- The **Science and Technology Centers Program** is designed to team scientists and engineers to focus on research with a long-term technological horizon and promote linkages with industry and other sectors.

Other center programs also foster industry-university collaboration. The **Supercomputer Centers** have close links with industry to facilitate the use of supercomputers. The **Materials Research Laboratories,** because of their focus on interdisciplinary programs in materials research, have proven attractive to industry. The **National Center for Atmospheric Research** has developed an active program of research in atmospheric phenomena relevant to aviation technology that receives considerable industrial support. The new **State University/Industry Cooperative Research Centers** program aims to enhance local economic development and actively focuses on technology transfer and knowledge deployment, especially with regard to small firms.

A number of programs under the jurisdiction of NSF's Engineering Directorate support research aimed at developing and/or perfecting manufacturing technologies and/or improving the speed and efficiency by which the results of NSF-sponsored (and other) research and technology are transferred to the marketplace. Included in this group (in addition to the already noted Engineering Research Centers program) are the **Industrial Innovation Interface Programs, Design and Manufacturing Systems Programs,** the **Strategic Manufacturing Initiative,** the **Small Business Innovation Research (SBIR) Program,** and a newly revived **Management of Technology Program.** The SBIR program, which originated in NSF, has served as a model for the national congressionally mandated program. Many SBIR awards utilize academic personnel and have generated process and product advances having considerable market impact.

NSF also funds small groups of investigators collaborating across disciplines. For example, participants in the Biotechnology Group and the Strategic Manufacturing Group perform research likely to produce technological advancements important to industry. There are also four relatively new initiatives in the single-investigator programs which focus on industry-university collaboration at the individual investigator level. Two of these programs—the Management of Technology Program and the Strategic Manufacturing Initiative—were identified above. The other programs are the **Decision, Risk, and Management Science Program** in the Social, Behavioral, and Economic Sciences Directorate (SBE) and the **Environmentally Benign Chemical Synthesis and Processing Initiative** between the Chemistry and the Chemical and Thermal Systems Divisions.

The Decision, Risk, and Management Science Program supports research aimed at improving decision-making under conditions of risk and uncertainty. Within this program is a **Joint NSF/Private Sector Research Initiative** wherein matching funding is available to investigators with private sector support to conduct research in the areas of operational control, management systems, and strategic planning. The Economics Program within SBE also supports research on corporate behavior.

The Division of Science Resources Studies in SBE sponsors several surveys that produce both funding and personnel data on industrial science and technology. Part I of this report contains information collected with these surveys.

In addition, SBE divisions fund and support the dissemination of research

- in the economics, public policy development, social impact, and management of technological change, and the building and testing of theories, models, and methodologies; and

- on the interrelationships among industry R&D and competitiveness, international technology transfer, international interdependencies, and the development of additional critical science and engineering indicators.

Recent examples of these programs are **Research on Methods to Estimate the Supply and Demand of U.S. Scientists and Engineers**, a new **Center for Survey Methods**, and a new program on **Research on Science and Technology**. The latter will support studies of particular interest to the industrial community, including studies of processes, inputs, outputs, and impacts in areas such as industrial research, university-industry interactions, the payoff to industrial innovation from academic research, knowledge/know-how/technology transfer, utilization, and diffusion.

NSF also participates in the **Federal Coordinating Council for Science, Engineering, and Technology** (FCCSET). A number of the interagency initiatives coordinated through FCCSET target technologies of key interest to industry, including high-performance computing and communications, advanced materials and processing, biotechnology, and a new initiative, Manufacturing Technologies.

In addition, NSF will be monitoring the new **Critical Technologies Institute** that will be responsible for identifying near- and long-term R&D objectives and for providing options for achieving those objectives.

What More Needs to Be Done

As the above examples indicate, within its mandate to support science and engineering education and academic basic research, NSF includes a broad range of programs and initiatives that contribute both directly and indirectly to industrial needs. The Committee fully endorses this broad range of programs and initiatives and NSF's recent efforts to further enhance industrial participation in its programs.

The Committee believes that NSF can further strengthen the direct impact of academic research on industrial competitiveness through the following actions.

- **Creating new fundamental science and engineering research initiatives that contribute to emerging and precompetitive technologies.** While the Directorates of Engineering and of Computer and Information Science and Engineering will be the likely home of many such new initiatives, other Directorates—including Education and Human Resources, the new Social, Behavioral, and Economic Sciences Directorate, and the traditional research directorates—are also likely candidates for programs that would benefit the development of emerging and precompetitive technologies.

- **Increasing support for strategic scientific and engineering research programs and initiatives, particularly for activities that attract industrial cosupport.** These include centers, cooperative multi-user facilities, consortia, and individual investigator projects with coparticipation by industry.

- **Following through on the recommendations of a National Academy of Engineering (NAE) evaluation of the NSF Engineering Research Centers Program, especially "a renewed effort to achieve original funding targets of the program."** According to the evaluation, "if the Federal Government is to assist industry in its fight to remain competitive, this is precisely the kind of program that it should support" (NAE 1989).

- **Significantly expanding and enhancing the effectiveness, scope, and outreach of its Engineering Research Centers, Science and Technology Centers, Industry/University Cooperative Research Centers, and other industry-related programs and coupling these even more closely with future industry needs.**

- **Promoting activities that specifically encourage more rapid knowledge transfer among researchers in academia, industry, and other sectors.** Efforts could be made to advance the capabilities of NSFNET (the Foundation's nationwide computer network) for scientific and technical information exchange.

- **Increasing support of research and education on engineering design, manufacturing processes, and programs that emphasize systems integration in engineering education.**

- **Encouraging and assisting in the expansion of Federal support of fundamental engineering research.**

While the managerial context for technology has not been a subject within the traditional realm of NSF responsibilities, NSF has identified a new Management of Technology Program as an area where it can make a meaningful contribution. In the context of this new program, NSF may want to broaden its traditional focus on the education of future scientists and engineers to include the education of future corporate leaders of both high-technology and traditional industries. NSF could support business and engineering schools in expanding their curricula to include integrated instruction in technology and management that would provide students with a better understanding of the R&D process and the importance of skillful technology planning and management to commercial success. A program also could be established to encourage and facilitate the introduction of courses tailored to meet the needs of recent engineering and business graduates by providing them with the management skills necessary to lead technology-based companies. NSF could also assist corporate leaders by supporting and disseminating research conducted to determine how some companies have mitigated the constraints imposed by external financial pressures.

The Committee therefore recommends that

- The Director examine NSF's role with respect to the managerial context for technology. For example, should NSF encourage the development of new kinds of university programs that integrate engineering and management education programs? Any significant changes in this direction would represent a substantial departure from NSF's traditional role, and thus should be given careful examination.

Both NSF and the Department of Commerce should anticipate increased demand for information on science- and technology-related subjects from policymakers in the Office of Management and Budget, OSTP, and other executive branch agencies and from Congress, and should begin developing and instituting procedures and mechanisms for responding to such requests as expeditiously as possible.

The Committee therefore recommends that

- NSF should develop an integrated program to
  - explore ways of correcting existing deficiencies in ongoing data collection activities;
  - identify missing information of value to policymakers and develop valid indicators of that information; and
  - determine the feasibility of collecting, analyzing, and disseminating the information.

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Appendix A
Statistical Tables

Table A-1. Trends in industrial R&D performance, by source of funds: 1953-90 and 1991-92 (est.)

[Dollars in millions]

Year	Total R&D		Federal		Company(1)	
	Current dollars	Constant 1987 dollars	Current dollars	Constant 1987 dollars	Current dollars	Constant 1987 dollars
1953	$3,630	NA	$1,430	NA	$2,200	NA
1954	4,070	NA	1,750	NA	2,320	NA
1955	4,640	NA	2,180	NA	2,460	NA
1956	6,605	NA	3,328	NA	3,277	NA
1957	7,731	NA	4,335	NA	3,396	NA
1958	8,389	NA	4,759	NA	3,630	NA
1959	9,618	37,585	5,635	22,020	3,983	15,565
1960	10,509	40,388	6,081	23,370	4,428	17,018
1961	10,908	41,554	6,240	23,771	4,668	17,783
1962	11,464	42,712	6,434	23,972	5,029	18,737
1963	12,630	46,451	7,270	26,738	5,360	19,713
1964	13,512	48,868	7,720	27,920	5,792	20,948
1965	14,185	49,930	7,740	27,244	6,445	22,686
1966	15,548	52,974	8,332	28,388	7,216	24,586
1967	16,385	54,130	8,365	27,635	8,020	26,495
1968	17,429	54,894	8,560	26,961	8,869	27,934
1969	18,308	54,897	8,451	25,340	9,857	29,556
1970	18,067	51,429	7,779	22,143	10,288	29,286
1971	18,320	49,527	7,666	20,725	10,654	28,802
1972	19,552	50,353	8,017	20,646	11,535	29,706
1973	21,249	51,488	8,145	19,736	13,104	31,752
1974	22,887	50,996	8,220	18,316	14,667	32,680
1975	24,187	49,171	8,605	17,493	15,582	31,677
1976	26,997	51,649	9,561	18,292	17,436	33,358
1977	29,825	53,383	10,485	18,767	19,340	34,616
1978	33,304	55,240	11,189	18,559	22,115	36,681
1979	38,226	58,316	12,518	19,097	25,708	39,219
1980	44,505	62,062	14,029	19,564	30,476	42,499
1981	51,810	65,699	16,382	20,774	35,428	44,925
1982	58,650	70,021	18,545	22,141	40,105	47,881
1983	65,268	74,883	20,680	23,726	44,588	51,156
1984	74,800	82,153	23,396	25,696	51,404	56,457
1985	84,239	89,265	27,196	28,818	57,043	60,446
1986	87,823	90,614	27,891	28,777	59,932	61,837
1987	92,155	92,155	30,752	30,752	61,403	61,403
1988	97,889	94,260	32,117	30,926	65,772	63,334
1989	101,854	93,944	31,292	28,862	70,562	65,082
1990	104,344	92,446	30,580	27,093	73,764	65,353
1991 (NSF est.)	106,750	91,161	30,400	25,961	76,350	65,201
1992 (NSF est.)	110,300	91,346	31,300	25,921	79,000	65,424

(1) Company funds include funds for industrial R&D work performed within company facilities in the U.S. from all sources except the Federal Government. These sources may include other companies, research institutions, colleges and universities, other nonprofit organizations, and state and local governments, as well as companies' own funds. Company-financed R&D not performed within the company is excluded.

NA = Not available

NOTE: The 1987 GDP implicit price deflator was used to convert current dollars to constant dollars.

SOURCES: National Science Foundation, Survey of Industrial Research and Development and NSF Panel on Industrial Science and Technology

Table A-2. National expenditures for R&D, by performing sectors and sources of funds: 1953-92 (page 1 of 2)

[In millions of dollars]

		Federal Govt.	Industry (2)			Universities & colleges					U&C FFRDCs	Other nonprofit institutions (2)			
				Sources			Sources						Sources		
Year	United States	Total used (1)	Total used	Fed. Govt.	Industry (3)	Total used	Fed. Govt.	Industry	U&Cs (4)	Nonprofits	Total used (5)	Total used	Fed. Govt.	Industry	Nonprofits (4)
1953.........	$5,124	$1,010	$3,630	$1,430	$2,200	$255	$138	$19	$72	$26	$121	$108	$54	$26	$28
1954.........	5,644	1,020	4,070	1,750	2,320	290	160	22	80	28	141	123	61	31	31
1955.........	6,172	905	4,640	2,180	2,460	312	169	25	88	30	180	135	68	35	32
1956.........	8,364	1,041	6,605	3,328	3,277	372	213	29	96	34	194	152	77	37	38
1957.........	9,775	1,220	7,731	4,335	3,396	410	229	34	109	38	240	174	86	37	51
1958.........	10,711	1,374	8,389	4,759	3,630	456	254	39	121	42	293	199	99	38	62
1959.........	12,357	1,639	9,618	5,635	3,983	526	306	39	134	47	338	236	127	42	67
1960.........	13,520	1,723	10,509	6,081	4,428	646	405	40	149	52	360	282	166	48	68
1961.........	14,320	1,878	10,908	6,240	4,668	763	500	40	165	58	410	361	226	49	86
1962.........	15,392	2,096	11,464	6,435	5,029	904	613	40	185	66	470	458	295	54	109
1963.........	17,059	2,279	12,630	7,270	5,360	1,081	760	41	207	73	530	539	365	55	119
1964.........	18,854	2,838	13,512	7,720	5,792	1,275	917	40	235	83	629	600	433	55	112
1965.........	20,044	3,093	14,185	7,740	6,445	1,474	1,073	41	267	93	629	663	477	62	124
1966.........	21,846	3,220	15,548	8,332	7,216	1,715	1,261	42	304	108	630	733	525	70	138
1967.........	23,146	3,396	16,385	8,365	8,020	1,921	1,409	48	345	119	673	771	552	74	145
1968.........	24,605	3,494	17,429	8,560	8,869	2,149	1,572	55	390	132	719	814	582	81	151
1969.........	25,629	3,501	18,308	8,451	9,857	2,225	1,600	60	420	145	725	870	616	93	161
1970.........	26,134	4,079	18,067	7,779	10,288	2,335	1,647	61	462	165	737	916	649	95	172
1971.........	26,676	4,228	18,320	7,666	10,654	2,500	1,724	70	529	177	716	912	630	98	184
1972.........	28,476	4,589	19,552	8,017	11,535	2,630	1,795	74	574	187	753	952	653	101	198
1973.........	30,718	4,762	21,249	8,145	13,104	2,884	1,985	84	613	202	817	1,006	690	105	211
1974.........	32,863	4,911	22,887	8,220	14,667	3,022	2,032	95	676	219	865	1,178	822	115	241
1975.........	35,213	5,354	24,187	8,605	15,582	3,409	2,288	113	749	259	987	1,276	875	125	276
1976.........	39,018	5,769	26,997	9,561	17,436	3,729	2,512	123	809	285	1,147	1,376	925	135	316
1977.........	42,783	6,012	29,825	10,485	19,340	4,067	2,726	139	888	314	1,384	1,495	987	150	358
1978.........	48,128	6,810	33,304	11,189	22,115	4,625	3,059	170	1,037	359	1,717	1,672	1,100	165	407
1979.........	54,953	7,418	38,226	12,518	25,708	5,380	3,604	194	1,214	368	1,935	1,994	1,350	180	464
1980.........	62,610	7,632	44,505	14,029	30,476	6,077	4,104	236	1,334	403	2,246	2,150	1,450	200	500

Table A-2. National expenditures for R&D, by performing sectors and sources of funds: 1953-92 (page 2 of 2)

[In millions of dollars]

		Federal Govt.	Industry (2)			Universities & colleges					U&C FFRDCs	Other nonprofit institutions (2)			
				Sources			Sources						Sources		
Year	United States	Total used (1)	Total used	Fed. Govt.	Industry (3)	Total used	Fed. Govt.	Industry	U&Cs (4)	Nonprofits	Total used (5)	Total used	Fed. Govt.	Industry	Nonprofits (4)
1981.........	$71,868	$8,426	$51,810	$16,382	$35,428	$6,846	$4,565	$291	$1,554	$436	$2,486	$2,300	$1,550	$225	$525
1982.........	80,018	9,141	58,650	18,545	40,105	7,323	4,763	337	1,731	492	2,479	2,425	1,650	250	525
1983.........	89,139	10,582	65,268	20,680	44,588	7,877	4,983	388	1,929	577	2,737	2,675	1,850	275	550
1984.........	101,139	11,572	74,800	23,396	51,404	8,617	5,424	475	2,103	615	3,150	3,000	2,100	325	575
1985.........	113,819	12,945	84,239	27,196	57,043	9,687	6,057	559	2,376	695	3,523	3,425	2,400	375	650
1986.........	119,529	13,535	87,823	27,891	59,932	10,926	6,703	699	2,789	735	3,895	3,350	2,250	425	675
1987.........	125,353	13,413	92,155	30,752	61,403	12,154	7,333	789	3,201	831	4,206	3,425	2,200	450	775
1988.........	133,740	14,281	97,889	32,117	65,772	13,464	8,181	871	3,471	941	4,531	3,575	2,200	500	875
1989.........	140,763	15,121	101,854	31,292	70,562	15,009	8,984	998	3,946	1,081	4,729	4,050	2,500	550	1,000
1990.........	146,152	16,002	104,344	30,580	73,764	16,325	9,611	1,135	4,356	1,223	4,831	4,650	2,900	600	1,150
1991.........	150,800	16,500	106,750	30,400	76,350	17,450	10,100	1,250	4,750	1,350	5,000	5,100	3,200	650	1,250
1992.........	157,400	17,600	110,300	31,300	79,000	19,000	10,900	1,350	5,250	1,500	5,100	5,400	3,300	700	1,400

(1) Total funds used by Federal Government are from Federal sources.

(2) Expenditures for FFRDCs administered by industry and nonprofit institutions are included in the totals of the respective sectors.

(3) Industry R&D expenditures include all non-Federal sources of funds.

(4) Includes R&D funds from state and local government sources.

(5) Includes R&D expenditures only of FFRDCs administered by individual universities and colleges and by university consortia. In 1990, 99 percent of total funds used were from Federal sources.

NOTES: Data are based on annual reports by performers except for the nonprofit sector; R&D expenditures by nonprofit sector performers have been estimated since 1973 on the basis of a survey conducted in that year. Data are preliminary for 1991 and estimated for 1992. Data available to NSF's Division of Science Resources Studies as of May 14, 1992, have been incorporated.

KEY: FFRDCs = Federally funded research and development centers
U&Cs = Universities and colleges

SOURCES: National Science Foundation, "National Patterns of R&D Resources: 1992." Reported data were derived from "Research and Development in Industry: 1990"; "Academic Science/Engineering: R&D Expenditures, Fiscal Year 1990"; "Federal Funds for Research and Development: Fiscal Years 1990, 1991, and 1992"; and Aspen Systems Corporation prepared for NSF "Planned R&D Expenditures of Major U.S. Firms: 1991-1992"

Table A-3. Company and other (except Federal) funds for industrial R&D performance, by industry and size of company: 1980-90 (page 1 of 2)

[Dollars in millions]

Industry and size of company	SIC code	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Total..	....	$30,476	$35,428	$40,105	$44,588	$51,404	$57,043	$59,932	$61,403	$65,772	$70,562	$73,764
Distribution by industry												
Food, kindred, and tobacco products (1)................	20,21	(D)	636	777	824	1,081	1,136	1,280	1,204	1,192	1,284	1,376
Textiles and apparel..................................	22,23	(D)	116	136	150	182	218	246	243	210	(S)	(S)
Lumber, wood products, and furniture..................	24,25	(D)	161	159	152	143	147	144	137	156	172	180
Paper and allied products.............................	26	(D)	566	566	552	594	576	538	604	664	686	736
Chemicals and allied products.........................	28	4,264	5,205	6,197	6,792	7,736	8,310	8,664	9,445	10,573	11,383	12,498
Industrial chemicals................................	281-82,286	1,856	2,393	2,810	2,828	3,057	3,281	3,374	3,531	3,763	3,960	4,280
Drugs and medicines.................................	283	(D)	2,064	2,473	2,896	3,310	3,481	3,657	4,095	4,743	5,164	5,651
Other chemicals.....................................	284-85,287-89	653	747	914	1,068	1,369	1,548	1,633	1,819	2,067	2,259	2,567
Petroleum refining and extraction.....................	13,29	1,401	1,780	2,003	2,074	2,245	2,194	1,971	1,883	1,923	2,050	2,083
Rubber products.......................................	30	(D)	598	617	638	671	659	655	596	635	678	732
Stone, clay, and glass products.......................	32	(D)	411	472	586	705	825	941	985	826	863	893
Primary metals..	33	594	702	711	701	683	730	786	711	642	715	774
Ferrous metals and products.........................	331-32,3398-99	338	415	426	396	357	323	336	249	257	254	240
Nonferrous metals and products......................	333-36	256	287	285	305	326	407	450	462	385	461	534
Fabricated metal products.............................	34	501	545	565	634	773	780	800	633	687	664	675
Machinery...	35	5,254	6,124	7,227	7,911	9,312	10,721	10,701	10,577	11,992	13,478	13,804
Office, computing, and accounting machines...........	357	(D)	3,847	4,944	5,634	7,011	8,418	8,380	8,193	9,371	10,780	11,050
Other machinery, except electrical...................	351-56,358-59	(D)	2,277	2,283	2,277	2,301	2,303	2,321	2,384	2,621	2,698	2,754
Electrical equipment..................................	36	5,431	6,409	6,682	8,158	9,037	9,271	9,767	10,449	11,061	11,641	11,768
Radio and TV receiving equipment....................	365	346	358	364	324	362	350	133	139	139	84	93
Communication equipment.............................	366	2,367	2,975	3,555	4,500	5,147	5,174	5,117	5,455	5,675	5,820	5,533
Electronic components...............................	367	1,165	1,212	1,342	1,810	2,354	2,826	3,357	3,630	4,068	4,458	4,747
Other electrical equipment..........................	361-64,369	1,553	1,864	1,421	1,524	1,174	921	1,160	1,225	1,179	1,279	1,395
Transportation equipment..............................	37	6,958	7,739	8,621	8,991	10,406	12,092	13,567	13,462	14,162	15,083	14,992
Motor vehicles and motor vehicles equipment..........	371	4,300	4,219	4,321	4,754	5,384	6,164	7,171	7,167	7,769	8,725	8,550
Other transportation equipment......................	373-75,379	(D)	80	114	227	258	279	330	356	370	353	302
Aircraft and missiles...............................	372,376	2,570	3,440	4,186	4,010	4,764	5,649	6,066	5,939	6,023	6,005	6,140

Table A-3. Company and other (except Federal) funds for industrial R&D performance, by industry and size of company: 1980-90 (page 2 of 2)

[Dollars in millions]

Industry and size of company	SIC code	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Distribution by industry												
Professional and scientific instruments................	38	$2,456	$2,978	$3,407	$3,816	$4,211	$4,622	$4,752	$4,950	$5,306	5,630	$6,064
Scientific and mechanical measuring instruments......	381-82	1,001	1,235	1,363	1,605	1,671	1,596	1,521	1,598	1,710	1,858	2,076
Optical, surgical, photographic, and other instruments..	383-87	1,454	1,743	2,044	2,211	2,540	3,026	3,231	3,352	3,596	3,772	3,988
Other manufacturing industries (1).....................	27,31,39	339	411	493	525	373	361	380	380	383	400	445
Nonmanufacturing industries...........................	10-11,14-17,40-42,44-51,53-54,56,60,62-63,72-73,78,806-07,87	1,037	1,048	1,472	2,084	3,252	4,401	4,740	5,144	5,360	5,620	6,515
Distribution by size of company [Based on number of employees]												
Less than 500..	....	1,711	1,880	2,411	3,781	3,781	5,127	6,203	6,200	(S)	(S)	(S)
500 to 999...	....					1,341	1,531	1,765	1,610	1,517	1,660	1,817
1,000 to 4,999.......................................	....	2,257	2,586	3,241	3,438	4,618	5,249	6,243	6,281	6,441	6,646	6,538
5,000 to 9,999.......................................	....	1,596	2,369	2,224	2,080	2,764	3,350	3,455	3,753	4,322	4,815	5,867
10,000 to 24,999.....................................	....	4,867	5,537	6,448	7,228	8,546	8,366	8,489	9,681	9,668	8,948	10,222
25,000 or more.......................................	....	20,045	23,056	25,781	28,061	30,354	33,421	33,778	33,878	37,438	41,860	42,137

(1) Until 1984, tobacco products (SIC 21) were included with "other manufacturing industries."

(D) Data have been withheld to avoid disclosing operations of individual companies.

(S) Data have been withheld due to imputation of more than 50 percent.

NOTE: Company funds include funds for industrial R&D work performed within company facilities in the U.S. from all sources except the Federal Government. These sources may include other companies, research institutions, colleges and universities, other nonprofit organizations, and state and local governments, as well as companies' own funds. Company-financed R&D not performed within the company is excluded.

SOURCE: National Science Foundation, Survey of Industrial Research and Development

Table A-4. Rates of change in industrial R&D spending: 1975-80, 1980-85, 1985-90, and 1990-92

Industry	SIC code	Average annual real change in industrial R&D spending [percent] 1975-80	1980-85	1985-90	1990-92 (est.)
Total		6.1 %	7.3 %	1.6 %	0.1 %
Chemicals and allied products	28	3.3	8.2	4.7	3.2
Industrial and other chemicals	281-82,284-89	2.4 (1)	7.9	3.5	-0.8
Drugs and medicines	283	4.2 (1)	8.5	6.3	7.8
Petroleum refining and extraction	13,29	6.8 (1)	3.5	-4.5	-1.7
Machinery	35	6.0	9.2	1.5	-0.2
Office, computing, and accounting machines	357	6.3	13.2	1.9	-0.4
Other machinery, except electrical	351-56,358-59	5.5	-0.8	0.0	0.4
Electrical equipment	36	5.9	5.3	1.2	-1.8
Communication equipment	366	4.1	10.7	-2.2	NA
Electronic components	367	17.4 (2)	13.0	7.0	NA
Other electrical equipment	361-65,369	2.7 (2)	-12.6	-0.4	NA
Transportation equipment	37	7.3	5.7	0.7	NA
Motor vehicles and motor vehicles equipment	371	7.8	1.7	3.0	-0.5
Aircraft and missiles	372,376	6.5	10.8	-1.9	-1.0
Professional and scientific instruments	38	11.0	7.4	1.9	NA
Scientific and mechanical measuring instruments	381-82	22.3	3.9	1.7	-1.0
Optical, surgical, photographic, and other instruments	383-87	5.9	9.6	2.0	NA
Nonmanufacturing industries	08,10-12,14-17, 40-67,72-73, 806-07,891	10.9	26.4	4.4	NA

(1) Estimated by NSF staff.

(2) Average annual real change for 1974-80.

NA = Not available

NOTE: The 1987 GDP implicit price deflator was used to convert current dollars to constant dollars.

SOURCES: National Science Foundation, Survey of Industrial Research and Development and NSF Panel on Industrial Science and Technology

Table A-5. Company and other (except Federal) R&D funds as a percentage of net sales in R&D-performing manufacturing companies, by industry and size of company: 1980-90 (page 1 of 2)

Industry and size of company	SIC code	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Total..	....	2.1 %	2.2 %	2.6 %	2.6 %	2.6 %	3.0 %	3.2 %	3.1 %	3.1 %	3.2 %	3.2
Distribution by industry												
Food, kindred, and tobacco products (1)............	20,21	(D)	0.4	0.4	0.4	0.4	0.6	0.6	0.6	0.5	0.5	0.5
Textiles and apparel................................	22,23	(D)	0.4	0.5	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.4
Lumber, wood products, and furniture................	24,25	0.8	0.8	0.8	0.8	0.7	0.8	0.6	0.6	0.7	0.7	0.7
Paper and allied products...........................	26	1.0	1.0	1.1	0.9	0.8	0.8	0.7	0.6	0.7	0.7	0.8
Chemicals and allied products.......................	28	3.3	3.4	4.0	4.2	4.6	4.9	5.1	5.2	5.3	5.3	5.7
Industrial chemicals.............................	281-82,286	2.8	2.8	3.5	3.4	3.8	4.2	4.4	4.4	4.3	4.3	4.5
Drugs and medicines..............................	283	6.1	6.3	7.0	7.7	8.2	8.0	8.4	8.7	9.0	9.1	9.8
Other chemicals..................................	284-85,287-89	1.9	2.1	2.3	2.5	2.9	3.1	3.3	3.3	3.5	3.4	3.9
Petroleum refining and extraction..................	13,29	0.5	0.6	0.8	0.7	0.7	0.9	1.1	1.0	1.0	1.0	0.8
Rubber products....................................	30	(D)	1.9	1.7	1.7	1.9	1.8	1.7	1.6	1.6	1.7	1.8
Stone, clay, and glass products....................	32	1.3	1.4	1.7	1.9	1.9	2.3	2.4	2.5	2.2	2.3	2.3
Primary metals.....................................	33	0.5	0.7	0.8	0.8	0.9	0.9	1.0	0.9	0.8	0.9	1.0
Ferrous metals and products......................	331-32,3398-99	0.5	0.6	0.6	0.6	0.6	0.5	0.7	0.6	0.6	0.6	0.6
Nonferrous metals and products...................	333-36	0.6	1.0	1.3	1.2	1.2	1.4	1.5	1.3	1.1	1.2	1.5
Fabricated metal products..........................	34	1.2	1.2	1.2	1.3	1.4	1.4	1.4	1.2	1.0	1.0	1.0
Machinery..	35	4.5	4.4	5.0	5.4	5.8	6.7	7.3	7.1	7.2	8.0	8.4
Office, computing, and accounting machines.......	357	10.4	9.7	10.4	10.0	10.5	12.4	12.4	12.3	11.5	13.5	15.4
Other machinery, except electrical...............	351-56,358-59	2.2	2.3	2.4	2.4	2.5	2.6	2.9	3.0	3.1	3.0	3.0
Electrical equipment...............................	36	3.9	4.2	4.4	5.0	4.5	4.8	5.1	5.4	5.2	4.9	4.9
Radio and TV receiving equipment.................	365	2.7	2.6	3.3	2.9	3.7	4.3	3.6	3.2	3.0	2.8	3.1
Communication equipment..........................	366	5.4	6.0	6.7	7.2	5.1	5.4	5.2	5.5	5.4	5.3	4.9
Electronic components............................	367	5.9	5.7	5.2	6.6	6.6	8.2	9.2	8.5	8.0	8.0	8.6
Other electrical equipment.......................	361-64,369	2.5	2.8	2.3	2.6	2.2	2.0	2.2	2.6	2.4	2.0	2.2
Transportation equipment	37					3.3	3.4	3.6	3.4	3.5	3.7	3.7
Motor vehicles and motor vehicles equipment.......	371	4.2	3.9	4.0	3.5	3.0	3.1	3.3	3.4	3.4	3.8	3.9
Other transportation equipment...................	373-75,379	0.3 %	0.3 %	0.7 %	1.7 %	2.0 %	2.3 %	2.7 %	2.5 %	2.5 %	2.3 %	1.9
Aircraft and missiles............................	372,376	3.8	4.6	5.1	4.1	4.0	3.9	4.0	3.6	3.6	3.6	3.5

Table A-5. Company and other (except Federal) R&D funds as a percentage of net sales in R&D-performing manufacturing companies, by industry and size of company: 1980-90 (page 2 of 2)

Industry and size of company	SIC code	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Professional and scientific instruments............	38	6.1	6.7	7.3	7.7	7.6	8.3	8.2	7.5	7.3	7.3	7.6
Scientific and mechanical measuring instruments...	381-82	6.2	6.9	7.6	8.8	8.3	8.4	8.4	8.1	8.4	8.5	9.4
Optical, surgical, photographic, and other instruments....................................	383-87	6.0	6.6	7.1	7.1	7.3	8.1	8.0	7.2	6.9	6.9	6.9
Other manufacturing industries (1)..................	27,31,39	0.4	0.4	0.8	1.0	1.1	1.0	1.2	1.1	1.1	1.0	1.1
Distribution by size of company [Based on number of employees]												
Less than 500....................................	....	1.2	1.4	1.6	2.2	2.8	3.4	4.0	3.8	3.6	3.6	3.6
500 to 999..	....					2.2	2.2	2.2	2.2	2.1	1.6	1.8
1,000 to 4,999....................................	....	1.4	1.5	1.7	2.0	2.0	2.4	2.4	2.4	2.1	2.0	2.1
5,000 to 9,999....................................	....	1.1	1.7	1.5	1.3	1.6	1.8	2.0	2.0	2.3	2.5	2.7
10,000 to 24,999..................................	....	1.4	1.6	2.0	2.3	2.5	2.5	2.6	2.5	2.6	2.4	2.7
25,000 or more....................................	....	2.5	2.7	3.3	3.4	3.2	3.5	3.7	3.8	3.8	3.7	3.8

(1) Until 1984, tobacco products, SIC 21, were included with "other manufacturing industries."

(D) Data have been withheld to avoid disclosing operations of individual companies.

SOURCE: National Science Foundation, Survey of Industrial Research and Development

Table A-6. R&D scientists and engineers per 1,000 employees in manufacturing companies, by industry and size of company: 1980-90 (page 1 of 2)

Industry and size of company	SIC code	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Distribution by industry												
Total..	....	27	29	33	34	40	43	45	45	47	49	49
Food, kindred,and tobacco products (1)...............	20,21	5	6	6	6	7	8	7	7	7	7	7
Textiles and apparel.................................	22,23	3	3	4	4	5	5	4	4	(S)	4	4
Lumber, wood products, and furniture................	24,25	6	(S)	(S)	(S)	6	6	5	5	5	5	5
Paper and allied products............................	26	14	16	14	12	13	13	11	11	11	11	12
Chemicals and allied products........................	28	42	44	51	54	57	57	70	68	70	72	73
Industrial chemicals..............................	281-82,286	36	37	44	45	41	39	56	52	55	56	57
Drugs and medicines...............................	283	60	66	74	(S)	89	81	98	98	99	98	104
Other chemicals...................................	284-85,287-89	30	33	37	39	51	62	63	61	61	63	64
Petroleum refining and extraction....................	13,29	17	20	22	22	22	21	19	20	24	25	25
Rubber products......................................	30	(S)	25	(S)	(S)	27	26	25	19	(S)	17	17
Stone, clay, and glass products......................	32	13	13	15	16	17	20	20	24	27	29	29
Primary metals.......................................	33	7	8	10	11	12	12	11	12	13	12	13
Ferrous metals and products.......................	331-32,3398-99	6	6	8	11	11	11	7	9	9	9	10
Nonferrous metals and products....................	333-36	12	13	13	13	16	16	17	16	17	16	16
Fabricated metal products............................	34	14	15	(S)	(S)	(S)	(S)	(S)	17	17	18	18
Machinery..	35	36	35	48	57	56	60	64	67	68	76	81
Office, computing, and accounting machines.........	357	72	71	80	88	90	99	107	115	116	133	143
Other machinery, except electrical.................	351-56,358-59	18	19	26	30	32	29	26	29	29	30	32
Electrical equipment.................................	36	44	48	55	51	49	53	59	65	70	70	73
Radio and TV receiving equipment..................	365	35	51	(S)	(S)	(S)	23	55	45	48	45	29
Communication equipment...........................	366	55	56	74	61	56	62	68	73	83	77	80
Electronic components..............................	367	55	66	66	(S)	(S)	81	82	86	102	105	111
Other electrical equipment.........................	361-64,369	32	34	(S)	(S)	30	30	26	28	26	26	30
Transportation equipment.............................	37					(S)	71	69	68	73	73	72
Motor vehicles and motor vehicles equipment........	371	30	30	31	30	27	28	38	42	41	43	45
Other transportation equipment.....................	373-75,379	9	9	12	(S)	(S)	8	23	38	39	47	49
Aircraft and missiles..............................	372,376	92	98	94	102	110	116	99	91	101	100	96

Table A-6. R&D scientists and engineers per 1,000 employees in manufacturing companies, by industry and size of company: 1980-90 (page 2 of 2)

Industry and size of company	SIC code	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Distribution by industry												
Professional and scientific instruments..............	38	39	46	(S)	(S)	(S)	(S)	(S)	71	70	76	71
Scientific and mechanical measuring instruments....	381-82	(S)	(S)	(S)	(S)	(S)	(S)	(S)	85	94	106	106
Optical, surgical, photographic, and other instruments.......................................	383-87	48	47	(S)	(S)	(S)	70	61	63	58	60	53
Other manufacturing industries (1)..................	27,31,39	7	7	9	(S)	(S)	(S)	(S)	18	18	16	13
Distribution by size of company [Based on number of employees]												
Less than 500..	....	25	28	30	34	42	50	59	59	58	59	55
500 to 999...	....					21	21	23	27	26	27	28
1,000 to 4,999.......................................	....	19	21	22	25	24	26	32	30	31	30	31
5,000 to 9,999.......................................	....	19	18	23	22	19	19	28	29	29	39	36
10,000 to 24,999.....................................	....	20	23	26	26	29	30	33	32	34	31	33
25,000 or more.......................................	....	34	36	43	42	47	49	56	57	58	62	62

(1) Until 1984, tobacco products, SIC 21, were included with "other manufacturing industries."

(S) Data have been withheld due to imputation of 50 percent or more.

NOTE: The number of R&D scientists and engineers per 1,000 employees for 1990 is derived by dividing the arithmetic mean of scientists and engineers employed in January 1990 and January 1991 by the number of employees in all activities in March 1990. Similar procedures were used for earlier years. Nonmanufacturing industries are included in pre-1983 calculations.

SOURCE: National Science Foundation, Survey of Industrial Research and Development

Table A-7. Share of global exports of high-technology products

Ranking	Microelectronics 1980	Microelectronics 1989	Computers 1980	Computers 1989	Telecommunications Equipment 1980	Telecommunications Equipment 1989	Aerospace 1980	Aerospace 1989
1	United States (18.3)	Japan (22.1)	United States (38.6)	United States (24.0)	West Germany (16.7)	Japan (29.7)	United States (47.6)	United States (45.8)
2	Japan (13.2)	United States (21.9)	West Germany (11.5)	Japan (17.5)	Sweden (15.3)	West Germany (9.5)	United Kingdom (19.7)	West Germany (12.5)
3	Singapore (10.1)	Malaysia (8.9)	United Kingdom (10.4)	United Kingdom (9.0)	United States (10.9)	United States (8.8)	West Germany (9.1)	United Kingdom (10.9)
4	Malaysia (8.9)	South Korea (7.4)	France (8.6)	West Germany (6.9)	Japan (10.3)	Sweden (8.1)	France (6.0)	France (10.2)
5	West Germany (8.4)	West Germany (5.8)	Italy (6.6)	Taiwan (5.8)	Netherlands (9.3)	Hong Kong (6.3)	Canada (4.4)	Canada (4.4)
6	France (4.9)	Singapore (5.6)	Japan (4.3)	Singapore (4.6)	Belgium (7.4)	United Kingdom (5.1)	Netherlands (2.5)	Italy (3.3)
7	Hong Kong (4.8)	United Kingdom (4.5)	Canada (3.4)	France (4.2)	France (6.5)	France (4.5)	Italy (2.1)	Netherlands (2.9)
8	United Kingdom (4.5)	Hong Kong (4.2)	Sweden (2.9)	Hong Kong (4.0)	Canada (5.1)	Canada (4.1)	Belgium (1.2)	Japan (1.1)
9	South Korea (4.2)	Taiwan (3.5)	Hong Kong (1.9)	Italy (3.7)	United Kingdom (4.1)	Taiwan (3.5)	Switzerland (0.8)	Belgium (1.0)
10	Philippines (3.8)	France (3.1)	Netherlands (1.6)	Netherlands (3.6)	Italy (2.7)	South Korea (3.2)	Japan (0.6)	Sweden (1.0)

Ranking	Machine Tools and Robotics 1980	Machine Tools and Robotics 1989	Scientific/Precision Equipment 1980	Scientific/Precision Equipment 1989	Medicine and Biologicals 1980	Medicine and Biologicals 1989	Organic Chemicals 1980	Organic Chemicals 1989
1	West Germany (25.8)	Japan (23.8)	United States (28.3)	United States (25.2)	West Germany (16.7)	West Germany (15.6)	West Germany (19.1)	West Germany (17.0)
2	United States (14.1)	West Germany (20.8)	West Germany (18.1)	West Germany (18.5)	Switzerland (12.5)	Switzerland (12.2)	United States (13.9)	United States (15.5)
3	Japan (11.3)	United States (12.1)	United Kingdom (9.4)	Japan (12.9)	United Kingdom (12.0)	United States (12.2)	Netherlands (10.9)	France (8.7)
4	Switzerland (9.1)	Italy (10.0)	France (8.0)	United Kingdom (9.6)	France (11.9)	United Kingdom (11.8)	France (10.7)	Netherlands (8.1)
5	Italy (8.7)	Switzerland (8.4)	Japan (7.1)	France (5.6)	United States (11.4)	France (10.3)	United Kingdom (8.4)	United Kingdom (7.2)
6	United Kingdom (6.9)	United Kingdom (4.2)	Switzerland (5.5)	Switzerland (4.1)	Italy (5.4)	Italy (5.5)	Japan (6.3)	Japan (7.0)
7	France (6.3)	France (3.2)	Netherlands (4.2)	Netherlands (3.1)	Belgium (5.2)	Belgium (4.5)	Belgium (6.1)	Belgium (5.7)
8	Sweden (2.4)	Taiwan (2.3)	Italy (3.0)	Italy (3.1)	Netherlands (4.7)	Sweden (3.7)	Italy (4.6)	Italy (4.6)
9	Canada (1.8)	Sweden (2.0)	Belgium (2.7)	Sweden (2.4)	Sweden (2.5)	Netherlands (3.6)	Switzerland (3.3)	Switzerland (3.0)
10	Netherlands (1.8)	Belgium (1.9)	Sweden (2.7)	Canada (1.9)	Japan (2.2)	Japan (2.8)	Canada (2.5)	Canada (2.4)

Source: *CIA Handbook of Economic Statistics,* 1990

Table A-8. Worldwide sales of information systems, by producer base region: 1984 and 1988

Information system	1984 World sales (dollars in billions)	1984 Regional distribution (percent) N. Amer.	Europe	Japan	1988 World sales (dollars in billions)	1988 Regional distribution (percent) N. Amer.	Europe	Japan	Korea	Taiwan
All products	137.0	77	11	12	261.0	61	16	21	1	1
Mainframe	22.6	77	6	16	30.4	53	9	37	0	0
Mini	16.0	79	13	8	25.5	72	13	15	0	0
Micro	14.8	86	7	7	31.3	64	12	16	4	4
Datacomm	9.1	52	32	16	17.0	42	21	36	1	0
Peripherals	37.3	75	10	14	65.9	53	15	29	2	1
Software	10.3	76	14	10	23.1	70	17	13	0	0
Services	9.0	86	7	7	24.0	78	14	8	0	0
Maintenance	14.4	81	10	9	29.8	72	18	10	0	0
Other revenues	3.4	68	14	18	13.2	48	43	9	0	0

Notes: Compilation is from Datamation 100 and was supplemented by other industry sources. "0" means < 1 percent after rounding. Distribution of information system revenues by product segment has occasionally used 1987 data when 1988 data were unavailable. Compilations were based on data for 151 largest information systems companies. Workstations were counted as minicomputer sales. Amdahl, NAS, Zenith, and Wyse were counted as U.S. firms. Nihon Univac was counted as a Japanese firm. 1984 data cover 104 largest U.S. companies, 33 European companies, and 14 Japanese companies. 1988 data cover 100 largest U.S. companies plus Northern Telecom (Canada); 30 largest European; 19 largest Japanese; Acer & Mitec (Taiwan); and Samsung (Korea). The remainder of Taiwan and Korean computer industries were estimated and added in.

Source: Kenneth Flamm, *Globalisation in the Computer Industry*, Organisation for Economic Cooperation and Development, Paris, December 1990.

Table A-9. International R&D expenditures and R&D as a percentage of GDP: 1961-90

	R&D expenditures (1)							R&D expenditures as a percentage of GDP						
	United States	Japan	Germany	France	United Kingdom	Italy	Sweden	United States	Japan	Germany	France	United Kingdom	Italy	Sweden
	Billions of constant 1987 dollars							Percent						
1961....	54.6	NA	NA	NA	NA	NA	NA	2.7	1.4	NA	1.4	2.5	NA	NA
1962....	57.3	NA	NA	NA	NA	NA	NA	2.7	1.5	1.2	1.5	NA	NA	NA
1963....	62.7	6.2	NA	5.7	NA	2.0	NA	2.8	1.5	1.4	1.6	NA	0.6	NA
1964....	68.2	7.0	7.3	7.1	10.5	NA	0.9	2.9	1.5	1.6	1.8	2.3	NA	1.2
1965....	70.6	7.7	8.7	8.2	NA	2.2	NA	2.8	1.6	1.7	2.0	NA	0.7	NA
1966....	74.4	8.4	9.5	8.8	11.2	NA	NA	2.8	1.5	1.8	2.1	2.3	NA	NA
1967....	76.5	9.7	10.1	9.7	11.5	2.8	1.0	2.8	1.6	2.0	2.2	2.3	0.7	1.3
1968....	77.5	11.5	10.9	9.9	11.7	3.2	NA	2.8	1.7	2.0	2.1	2.2	0.8	NA
1969....	76.8	13.4	11.7	10.1	11.8	3.5	1.1	2.7	1.7	1.8	2.0	2.3	0.8	1.2
1970....	74.4	16.0	13.8	10.1	NA	3.9	NA	2.6	1.9	2.1	1.9	NA	0.8	NA
1971....	72.1	17.1	15.2	10.5	NA	4.1	1.4	2.4	1.9	2.2	1.9	NA	0.9	1.5
1972....	73.3	18.8	15.8	10.7	11.6	4.3	NA	2.4	1.9	2.2	1.9	2.1	0.9	NA
1973....	74.4	20.7	15.8	10.7	NA	4.3	1.6	2.3	2.0	2.1	1.8	NA	0.8	1.6
1974....	73.2	21.2	16.2	11.2	NA	4.2	NA	2.2	2.0	2.1	1.8	NA	0.8	NA
1975....	71.6	21.6	16.7	11.3	12.2	4.6	1.9	2.2	2.0	2.2	1.8	2.2	0.8	1.7
1976....	74.6	22.4	17.0	11.5	NA	4.5	NA	2.2	2.0	2.2	1.8	NA	0.8	NA
1977....	76.6	23.1	17.4	11.8	NA	4.7	1.9	2.2	2.0	2.2	1.8	NA	0.8	1.8
1978....	79.8	24.3	18.7	12.1	13.5	4.6	NA	2.1	2.0	2.3	1.8	2.2	0.7	NA
1979....	83.8	26.8	20.5	12.9	NA	4.9	2.1	2.2	2.1	2.4	1.8	NA	0.7	1.9
1980....	87.3	29.3	21.4	13.3	NA	5.1	NA	2.3	2.2	2.5	1.8	NA	0.8	NA
1981....	91.1	32.0	21.1	14.6	15.4	6.0	2.5	2.4	2.3	2.4	2.0	2.4	0.9	2.3
1982....	95.5	34.5	21.8	15.6	NA	6.2	NA	2.5	2.4	2.5	2.1	NA	0.9	NA
1983....	102.3	37.1	22.0	16.0	15.0	6.6	2.9	2.6	2.6	2.5	2.1	2.3	1.0	2.6
1984....	111.1	39.6	22.4	16.8	NA	7.1	NA	2.7	2.6	2.5	2.2	NA	1.0	NA
1985....	120.6	43.5	24.4	17.3	15.9	8.1	3.4	2.8	2.8	2.7	2.3	2.3	1.1	2.9
1986....	123.3	43.9	24.9	17.5	16.8	8.3	NA	2.8	2.8	2.7	2.2	2.3	1.1	NA
1987....	125.4	46.9	26.5	18.1	16.9	9.0	3.7	2.8	2.8	2.9	2.3	2.3	1.2	3.0
1988....	128.8	50.3	27.2	18.8	17.4	9.5	NA	2.7	2.9	2.9	2.3	2.2	1.2	NA
1989....	129.8	54.5	28.2	19.9	18.0	10.0	3.6	2.7	3.0	2.9	2.3	2.3	1.2	2.9
1990....	129.5	59.2	28.8	20.9	NA	11.1	NA	2.7	3.1	2.8	2.4	NA	1.4	NA

(1) Conversions of foreign currencies to U.S. dollars are calculated with OECD purchasing power parity exchange rates. Constant 1987 dollars are based on U.S. Department of Commerce GDP implicit price deflators.

NA = Not available

SOURCES: NSF, Division of Science Resources Studies; Organisation for Economic Cooperation and Development (OECD); International Monetary Fund; and national sources

Table A-10. International nondefense R&D expenditures and nondefense R&D as a percentage of GDP: 1971-90

	Nondefense R&D expenditures (1)							Nondefense R&D expenditures as a percentage of GDP						
	United States	Japan	Germany	France	United Kingdom	Italy	Sweden	United States	Japan	Germany	France	United Kingdom	Italy	Sweden
	Billions of constant 1987 dollars							Percent						
1971....	50.2	17.0	14.1	8.0	NA	4.0	NA	1.7	1.9	2.1	1.4	NA	0.8	NA
1972....	50.4	18.7	15.0	8.4	8.5	4.2	NA	1.6	1.9	2.1	1.5	1.5	0.8	NA
1973....	52.6	20.5	14.7	8.4	NA	4.2	NA	1.6	2.0	2.0	1.4	NA	0.8	NA
1974....	53.1	21.0	15.1	8.9	NA	4.1	NA	1.6	2.0	2.0	1.4	NA	0.8	NA
1975....	51.9	21.5	15.7	9.1	8.5	4.6	1.6	1.6	2.0	2.1	1.4	1.4	0.8	1.4
1976....	54.7	22.3	15.9	9.4	NA	4.4	NA	1.6	2.0	2.0	1.4	NA	0.8	NA
1977....	55.3	23.0	16.4	9.6	NA	4.7	1.6	1.6	2.0	2.0	1.4	NA	0.8	1.5
1978....	58.4	24.1	17.6	9.7	9.6	4.5	NA	1.6	2.0	2.1	1.4	1.5	0.7	NA
1979....	62.8	26.6	19.3	10.1	NA	4.8	1.8	1.6	2.1	2.2	1.4	NA	0.7	1.6
1980....	66.5	29.1	20.4	10.3	NA	5.1	NA	1.7	2.2	2.3	1.4	NA	0.7	NA
1981....	67.8	31.9	20.2	10.9	11.4	5.8	2.3	1.8	2.3	2.3	1.5	1.8	0.8	2.1
1982....	69.2	34.3	20.9	12.0	NA	6.1	NA	1.8	2.4	2.4	1.6	NA	0.9	NA
1983....	73.7	36.9	21.0	12.6	11.1	6.4	2.6	1.9	2.5	2.4	1.7	1.7	0.9	2.3
1984....	78.9	39.3	21.4	13.3	NA	6.7	NA	1.9	2.6	2.4	1.7	NA	1.0	NA
1985....	84.9	43.2	23.2	13.7	11.8	7.6	3.0	2.0	2.8	2.6	1.8	1.7	1.1	2.6
1986....	85.2	43.6	23.6	13.7	13.0	7.9	NA	1.9	2.7	2.6	1.8	1.8	1.1	NA
1987....	86.2	46.6	25.2	14.2	13.3	8.6	3.3	1.9	2.8	2.7	1.8	1.8	1.1	2.7
1988....	90.2	49.9	26.0	14.6	14.1	8.9	NA	1.9	2.8	2.7	1.8	1.8	1.1	NA
1989....	92.3	54.1	26.9	15.6	14.7	9.4	3.2	1.9	3.0	2.7	1.8	1.9	1.2	2.6
1990....	94.1	58.8	27.3	16.0	NA	10.7	NA	1.9	3.0	2.7	1.8	NA	1.3	NA

NA = Not available

(1) Nondefense expenditures estimated here as total R&D expenditures, generally reported by the R&D performers, minus goverment R&D funds for defense purposes, generally taken from national budget documents; that is, as reported by the R&D funders. Conversions of foreign currencies to U.S. dollars are calculated with OECD purchasing power parity exchange rates. Constant 1987 dollars are based on U.S. Department of Commerce GDP implicit price deflator.

SOURCES: NSF, Division of Science Resources Studies; Organisation for Economic Cooperation and Development (OECD); International Monetary Fund; and national sources

Table A-11. Government R&D support by socioeconomic objective: 1989

	United States	Japan	Germany	France	United Kingdom
	Percent				
Total	100.0	100.0	100.0	100.0	100.0
Defense	65.5	9.0	19.0	41.9	55.2
Civil space	7.3	11.1	8.5	8.7	3.8
Advancement of research	3.8	13.8	20.7	17.5	5.8
Health	12.9	4.8	5.2	3.7	6.2
Industrial development	0.2	8.1	19.0	15.0	10.3
Energy	3.9	39.2	9.5	4.0	4.0
Agriculture, forestry, and fishing	1.9	6.5	3.1	4.6	5.5
Other	4.5	7.6	14.9	4.5	9.2

NOTE: Data adjusted to exclude general university funds for Japan (43 percent of the government-funded R&D total), West Germany (33 percent), the United Kingdom (18 percent), and France (12 percent).

SOURCES: Organisation for Economic Cooperation and Development, NSF, and national sources for Japan

Appendix B
IRI Survey: Questionnaire and Results

IRI Survey Purpose and Design

To identify the factors adversely affecting U.S. industry's ability to compete in global markets for high-tech products, the Committee needed input from leading industrial R&D officials.[1] Preparatory to receiving this input, the Committee first identified potential factors in the erosion of U.S. technology leadership. It identified these factors based on

- presentations by Dr. Arden Bement, Dr. Joseph Morone, and others;[2]
- discussions among Committee members; and
- a review of recent literature.

Subsequently, the Committee identified five major categories with 6 to 10 factors under each that may be responsible for the erosion in U.S. technology leadership.

The Industrial Research Institute (IRI) was contacted, and it agreed to work with the Committee.[3] The Committee and IRI were interested in determining the relative importance of each of these categories and factors in maintaining U.S. technology leadership. IRI used the list prepared by the Committee to survey its membership; it agreed to share the survey results with the Committee.

The survey questionnaire, entitled "Potential Causes for the Erosion in U.S. Technology Leadership," was mailed in June 1990 to the 237 members of IRI with U.S. mailing addresses. (A copy of the questionnaire appears at the end of this appendix.) Completed questionnaires were received from 139 members.[4]

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[1]The information the Committee obtained is thus limited by the fact that it is based on the opinions of industrial R&D officials only; chief executive officers and other industry officials may perceive the problems differently.

[2]Dr. Bement prepared a list, "Potential Root Causes for the Decline in Technology Leadership of U.S. Industry." Dr. Morone, Associate Professor, School of Management, Rensselaer Polytechnic Institute, was a consultant to the Committee.

[3]IRI is an association of more than 250 companies. Its major function is to coordinate the study of problems confronting managers of industrial research and development. A company may join IRI if it (1) maintains a technical staff and research laboratory in the United States, and (2) engages primarily in industrial production. IRI membership includes R&D directors from most large U.S. R&D-performing companies. IRI member companies account for approximately 85 percent of industry-funded R&D in the United States.

[4]Instead of returning the survey forms, two IRI members wrote letters. One member wrote that his company was based in another country and he didn't think it appropriate for him to complete the questionnaire. (Other IRI members representing

IRI members were asked to rank both the five categories and the factors under each of the categories from highest to lowest in importance.[5] In addition, they were provided space to add other factors they felt were important but may have been omitted from the Committee's list. They were also asked to provide recommendations for addressing the problems responsible for the erosion in U.S. technology leadership and to identify their companies' major industry (or industries) and domestic employment size group. The main survey results are described below.

The Five Categories

The five major categories identified by the Committee that may be responsible for the erosion in U.S. technology leadership were

- general management practices,
- external financial pressures,
- changing global technological environment,
- technology management practices, and
- Federal technology policy.

General management practices and *external financial pressures* are more at fault for the erosion in U.S. technology leadership than are the other three factors, according to the industrial R&D officials who participated in the survey. *General management practices* and *external financial pressures* received 91 and 86 first and second place rankings, respectively, and 61—or 44 percent—of the respondents ranked these two categories first and second. (See table B-1.)

Table B-1. Ranking of the five major categories

Rank	Category	Average rank	No. of 1st places	No. of 2nd places	No. of last places
1	General management practices	2.0	50	41	1
2	External financial pressures	2.2	45	41	9
3	Changing global technological environment	3.4	18	11	31
4	Technology management practices	3.8	5	18	44
5	Federal technology policy	3.8	6	14	46

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

foreign-owned companies did respond to the survey, however.) Another IRI member, representing a company in the petroleum industry, wrote that his industry was not losing technology leadership.

[5]Not all respondents ranked every category, some did not rank all factors within a category, and a few gave identical rankings to some of the factors. Missing and duplicative rankings were imputed using statistical procedures designed to maximize respondents' ordinal placement of categories and factors and minimize bias.

Federal technology policy, which received only 6 first and 14 second place "votes," was ranked last (closely behind *technology management practices*). Although *Federal technology policy* was ranked below the other categories, it cannot be inferred that the R&D directors consider this category to be unimportant in contributing to the decline in U.S. technology leadership; they only consider it less important than the other four categories.

One respondent suggested that the reason *Federal technology policy* was ranked last is because the United States lacks a national technology policy. According to this R&D official, it is not surprising that the IRI members gave less consideration to something that has never existed and therefore has never influenced their decision-making.

Response by Industry and by Size of Company

There was relatively little variation in response by industry and by size of company. (See tables B-2 and B-3.)

General management practices and *external financial pressures* were ranked first and second, respectively, by all but three industries. Respondents from the transportation equipment and instruments industries gave first place rankings to *changing global technological environment* (ranked third overall); those from the computer industry ranked *technology management practices* first.

No industry ranked *Federal technology policy* first. It received one second place ranking—from the communication services industry. This relatively high ranking is probably attributable to judicially imposed restrictions on companies in this industry. One respondent stated that his company was "precluded from major R&D investment" because the Modified Final Judgment imposed by the Federal judiciary prohibited his company's access to certain markets. (The ban was recently lifted.) *Federal technology policy* received third place rankings from the drug; other machinery; instruments; and research, development, and testing services industries.

Table B-2. Ranking of the five major categories by industry

Industry	No. of responses*	Gen'l mgmt practices	External financial pressures	Changing global tech. environment	Tech. mgmt practices	Federal .tech. policy
All industries	127	1	2	3	4	5
Food, tobacco	11	1	2	4	3	5
Lumber, paper	6	1	2	3	4	5
Industrial chemicals	27	1	2	3	5	4
Drugs	10	2	1	4	5	3
Other chemicals	8	1	2	3	3	5
Petroleum	8	1	2	3	4	5
Rubber	4	1	2	5	3	4
Ferrous metals	5	1	2	3	5	4
Fabr. metal prod.	7	1	1	5	3	4
Other machinery	3	1	2	4	5	3
Computers	4	2	2	4	1	5
Electrical equip.	8	2	1	3	5	4
Transport. equip.	8	2	3	1	4	5
Instruments	3	2	4	1	4	3
Comm. svcs	4	2	1	5	4	2
Research, devel., and testing	3	2	1	5	3	2

*Two respondents did not identify their industries; six other respondents represent industries having fewer than three respondents.

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

Size of company made little difference in the ranking of the five categories. Almost all size groups gave *general management practices* and *external financial pressures* first and second place rankings.

Table B-3. Ranking of the five major categories by size of company

No. of domestic employees	No. of responses*	Gen'l mgmt practices	External financial pressures	Changing global tech. environment	Tech. mgmt practices	Federal tech. policy
All companies	127	1	2	3	4	5
Less than 1,000	5	1	2	3	4	5
1,000 - 4,999	21	1	2	4	3	5
5,000 - 9,999	14	2	1	4	5	3
10,000 - 24,999	36	1	1	3	4	5
25,000 - 49,000	26	1	3	2	4	4
More than 50,000	24	1	2	3	4	5

*One respondent did not select a company-size group.

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

General Management Practices

Survey respondents placed greatest emphasis on "short time horizons" and "management by the numbers rather than by strategic vision," ranking these two factors first and second, respectively, under the *general management practices* category. (See table B-4.) "Short time horizons"received 89 first and second place rankings, and "management by the numbers" received 81; 51—or 37 percent—of the respondents gave first and second place rankings to these two management practices that are usually associated with external financial pressures.

Several factors—e.g., "over-concern for shareholder value"—added to this category by the respondents allude to the interrelationship between this category and the *external financial pressures* category. Institutional investors' large and growing dominance in equity markets (and their impatience for quick returns), the high cost of capital, and the threat of unwelcome takeovers all create a financial environment in which long-term strategic investments in technology are likely to be sacrificed when there is an exaggerated emphasis on short-term profitability. The need for financial incentives that would induce management to adopt a longer term perspective was mentioned by one-third of those IRI members who added recommendations to their questionnaires.

"Failure and/or inability to integrate technology into business strategy" and "corporate executives' lack of scientific and technical insight and lack of experience in the management of science and technology" were fairly consistently ranked third and fourth.[6] Other factors cited by the respondents are closely related to these. These other factors are:

- inability of marketing and top management to recognize opportunities based on new technology,
- domestic myopia—do not see the "globe" as a marketplace,
- too many lawyers and finance people in management positions, and
- "MBA syndrome" which encourages going for the top job—with little or no apprenticeship in understanding the nature of the company business and products.

Table B-4. Ranking of *general management practices*

Rank	Factor	Average rank	No. of 1st places	No. of 2nd places
1	Short time horizons	2.3	47	42
2	Management by the numbers rather than by strategic vision	2.3	47	34
3	Failure and/or inability to integrate technology into business strategy	3.0	22	30
4	Corporate executives' lack of scientific and technical insight and lack of experience in the management of science and technology	3.5	18	21
5	Executive talent reward structure	4.6	6	9
6	High rates of executive turnover	5.6	0	0

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

External Financial Pressures

Survey respondents overwhelmingly selected "growing dominance of institutional investors in equity markets and their demand for short term returns on their investments" as the most

[6] Several respondents added factors similar to these under the *technology management practices* category.

important factor in the category of *external financial pressures*. (See table B-5.) More than four out of five of the IRI members ranked this factor first or second.

Institutional investors—e.g., mutual funds and pension funds—have become a large and growing source of financing for U.S. firms. Their interest in maximizing the current value of their portfolios usually takes precedence over their interest in the long-term investment needs of the companies they are financing. The need for tax and other financial incentives to induce long-term holding by U.S. investors was frequently mentioned by the respondents in their recommendations.

"High cost of capital" finished a distant second in the ranking of factors under *external financial pressures*. Twelve IRI members addressed the cost of capital issue in their recommendations; most of these mentioned that reducing the budget deficit and increasing the savings rate would lower the cost of capital in the United States.

"Pressure to reduce debt accrued through leveraged buyouts and hostile takeovers," ranked fourth overall, was given high rankings by IRI members from companies that had experienced or were threatened by unwelcome raiders. This factor received 17 first place rankings, more than "growing costs of compliance with environmental, OSHA [Occupational Safety and Health Administration], and other Federal and state regulations," which was ranked third overall.

Table B-5. Ranking of *external financial pressures*

Rank	Factor	Average rank	No. of 1st places	No. of 2nd places
1	Growing dominance of institutional investors in equity markets and their demand for short term returns on their investments	1.7	80	33
2	High cost of capital	2.9	26	35
3	Growing costs of compliance with environmental, OSHA, and other Federal and state regulations that compete with and displace R&D investment	3.4	10	30
4	Pressures to reduce debt accrued through leveraged buyouts and hostile takeovers	3.5	17	22
5	Investment of "patient" capital inhibited by statutory separation of the managements of industrial and financial corporations (Glass-Steagal Act)	4.6	3	10
6	High cost of U.S. labor relative to that of other countries	4.9	4	2

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

Changing Global Technological Environment

There was less consensus in the IRI members' ranking of factors under *global technological environment* than was displayed in their ordering of the factors under the two previously discussed categories. Table B-6 shows a relatively small difference in the "average" rankings of the factors in this category. "Growing difficulty of controlling enough technological competitive advantage to sustain an entry barrier" was ranked highest, marginally ahead of the second-ranked factor, "declining lead times and faster product turnover cycles." These two factors received almost the same number of first and second place rankings and are closely related. Both are prominent characteristics of the electronics industry where rapid advancements in technology are continuously shortening product and process cycles, thus increasing the risk that companies will be unable to recover their investments fully and make a profit before their products become obsolete.

"Increasing number of skilled workers, including scientists and engineers, in other countries," ranked third overall, was considered to be the leading contributor to the *changing global technological environment* by 29 of the IRI officials. Several respondents added a factor to this category referring to the "increasingly effective collaboration between other countries' governments and industries to foster national economic growth."

Table B-6. Ranking of *changing global technological environment*

Rank	Factor	Average rank	No. of 1st places	No. of 2nd places
1	Growing difficulty of controlling enough technological competitive advantage to sustain an entry barrier	2.9	36	27
2	Declining lead times and faster product turnover cycles	3.0	35	27
3	Increasing number of skilled workers, including scientists and engineers, in other countries	3.4	29	23
4	Fragmented structure of some U.S. industries (e.g., semiconductor equipment manufacturing) not conducive to efficient and effective R&D and its commercialization	3.4	20	25
5	Shifts from leadership to fast-follower technology development strategies	3.7	13	18
6	Intensifying efforts of foreign companies to derive income from the licensing of intellectual properties	4.9	6	6

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

Technology Management Practices

"Relative slowness in product development and commercialization" was ranked first overall in the *technology management practices* category. (See table B-7.) This factor received 68 first, second, and third place rankings—less than the 74 received by "reluctance to invest in new enabling technologies because R&D may be too expensive, long-term, multi-industry, and interdisciplinary," which was ranked second overall.

"Failure to integrate R&D and marketing" was ranked third overall; it received 57 first, second, and third place votes. Nine respondents gave identical rankings to this factor, "failure to integrate R&D and manufacturing," and "failure to integrate design and manufacturing"; these three were listed sequentially on the questionnaire. (Five of the nine respondents gave first place rankings to these three factors.) Overall, "failure to integrate R&D and manufacturing" and "failure to integrate design and manufacturing" were ranked fourth and seventh, respectively. Respondents recommended that general and technology managers demand a closer linkage between design and manufacturing using techniques such as concurrent engineering and design for assembly.

A recurrent theme of recent literature on the erosion of the U.S. position in high-technology markets is "weakness in process technology." Apparently, however, the IRI officials do not perceive this as a major problem, compared to the other factors, because it was ranked sixth overall. Only 37 respondents gave this factor first, second, or third place rankings, and 13 of the 69 respondents who assigned rankings to all factors in this category ranked "weakness in process technology" last. Only three respondents mentioned the need to invest more in process R&D in their recommendations. "Weakness in process technology" may have been ranked higher if the survey had included a larger number of R&D officials representing electronics companies.[7] According to Steinmueller, continuous improvements in process technology are crucial in the integrated circuit industry where companies must be quick to implement state-of-the-art manufacturing innovations to remain competitive.

"Reluctance to commit significant resources to cooperative research for acquiring new technology" was ranked eighth overall. Only 33 respondents thought it was a major factor, ranking it first, second, or third. Also, 13 of those who ranked all 10 factors put it in last place. It can be inferred from the relatively low ranking of this factor that few major barriers prevent companies from participating in consortia, "centers of excellence," engineering research centers, joint ventures, and other cooperative activities to further the development of new technologies. The relatively low ranking of this factor is not surprising, because in the last few years (after passage of the National Cooperative Research Act of 1984), the number of joint ventures between domestic firms and with foreign partners has increased dramatically.[8] About one-fifth of the respondents recommended the establishment of more mechanisms to facilitate—and greater opportunities for—cooperation between industry, the government, and the academic sector. Several respondents recommended elimination of the "us versus them" attitude between government and the business community.

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[7]Also, more IRI members represent central corporate laboratories; process technology and R&D are seldom undertaken at such locations.

[8]The Office of Technology Administration of the U.S. Department of Commerce maintains a Research and Development Consortia Register under the National Cooperative Research Act of 1984.

Table B-7. Ranking of *technology management practices*

Rank	Factor	Average rank	No. of 1st places	No. of 2nd places	No. of 3rd places	No. of last places
1	Relative slowness in product development and commercialization	3.9	24	26	18	2
2	Reluctance to invest in new enabling technologies because the R&D may be too expensive, long-term, multi-industry, and interdisciplinary	3.9	47	14	13	3
3	Failure to integrate R&D and marketing	4.7	21	22	14	1
4	Failure to integrate R&D and manufacturing	5.5	12	11	10	0
5	"Big hit" mentality instead of focused, incremental development	5.8	10	14	12	5
6	Weakness in process technology	5.8	8	13	16	13
7	Failure to integrate design and manufacturing	5.9	8	10	11	3
8	Reluctance to commit significant resources to cooperative research for acquiring new technology	6.1	3	18	12	13
9	Bias toward internal development	6.9	4	4	11	16
10	High-performance/high-cost mentality	7.0	2	1	7	13

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

Federal Technology Policy

Two-thirds of the respondents gave first or second place rankings to "lack of long-term strategies for expanding the economy (and tax revenues) through technological competitiveness." (See table B-8.) The importance assigned to this factor can be interpreted as a statement (from most respondents) in favor of a comprehensive national technology strategy aimed at improving industrial competitiveness. Twenty-five of the IRI members mentioned the need for such a strategy in their recommendations.

The two factors that refer to education, "too little attention to the training of future scientists and engineers" and "too little attention to pre-college education," were ranked second and fourth, respectively. The need to strengthen the U.S. educational system was mentioned more frequently than any other respondent recommendation.

Two factors frequently included in discussions of competitiveness issues—"too much investment in defense, too little investment in civilian R&D activities" and "hands-off attitudes of government officials"—were ranked third and fifth, respectively. Eleven respondents mentioned the need to channel the revenue saved from any cutbacks in defense spending into the educational system and/or nondefense R&D. Twenty-eight respondents thought the Federal Government should take a more active role in arresting the decline in technology leadership by providing (1) support for emerging technologies or critical industries and (2) more financial incentives and opportunities for cooperative research by government, industry, and the academic sector. (Two respondents explicitly stated that the government had no role in industrial research and development.)

Table B-8. Ranking of *Federal technology policy*

Rank	Factor	Average rank	No. of 1st places	No. of 2nd places	No. of last places
1	Lack of long-term strategies for expanding the economy (and tax revenues) through technological competitiveness	2.4	58	31	3
2	Too little attention to the training of future scientists and engineers	3.8	16	23	5
3	Too much investment in defense, too little investment in civilian R&D activities	4.0	23	17	15
4	Too little attention to pre-college education	4.0	15	21	15
5	Hands-off attitudes of government officials toward joint government-industry investments in emerging or endangered technologies and/or lack of sufficient funding for newly created mechanisms, e.g., the National Institute of Standards and Technology's Advanced Technology Program	4.2	23	14	11
6	Inability to support emerging technology areas that cut across government agencies	4.8	0	15	15
7	Lengthy, ineffective enforcement of Federal laws against patent infringement and dumping	5.2	5	7	31

Sources: Industrial Research Institute and NSB Committee on Industrial Support for R&D

The respondents added more factors to this category than to any of the others:

- ineffective enforcement of reciprocal free and fair international trade practices;
- regulatory laws that slow technology commercialization and new product clearance;
- laws that permit high product liability exposure;

- lack of state and local strategies for expanding the economy through the technological infrastructure;
- tax laws that discourage investment in capital-intensive industries (in other countries, companies can write off their investments faster and install new technology sooner);
- lack of tax incentives for research;
- instability of Federal funding and increased insistence on annual funding such that too much time is spent in winning and reporting on contracts and not enough on doing creative R&D;
- antitrust laws; and
- Modified Final Judgment restrictions on Bell operating companies.

Summary

The overwhelming majority of IRI member officials participating in the survey held *general management practices* and *external financial pressures* responsible for the erosion in U.S. technology leadership. *Changing global technological environment* and *technology management practices* were ranked third and fourth, respectively. *Federal technology policy* was judged to have the least impact on maintaining U.S. technological supremacy compared to the other four categories.

"Short time horizons" and "management by the numbers rather than by strategic vision" received far more first and second place rankings than any of the other four factors listed under the *general management practices* category. Under *external financial pressures*, "growing dominance of institutional investors in equity markets and their demand for short term returns on their investments" was ranked first by most respondents; "high cost of capital" finished a distant second. Compared to the categories ranked first and second, there was a weaker consensus in the ranking of factors under the categories *changing global technological environment* and *technology management practices*. "Growing difficulty of controlling enough technological competitive advantage to sustain an entry barrier" and "relative slowness in product development and commercialization" were ranked first under each of these two categories, respectively. "Lack of long-term strategies for expanding the economy (and tax revenues through technological competitiveness)" was an easy winner under the *Federal technology policy* category.

There was little variation in response by industry and size of company, with the following exceptions:

- Based on the ranking of factors under *Federal technology policy*, it would appear that respondents from the largest companies are more likely than those from smaller companies

to believe that the U.S. Government's hands-off policy toward investment in emerging technologies is a major impediment in the race to develop and commercialize new technologies.

- Similarly, respondents from several of the major R&D-performing industries—i.e., electrical equipment, computers, instruments, and communication services—were more likely than those from less R&D-intensive industries to favor an expanded role for the Federal Government in assisting industrial science and technology.

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Industrial Research Institute, Inc.

June 8, 1990

Dear IRI Colleague:

Concern is growing over the threat to U.S. technology leadership from other industrialized nations. Unfortunately, instead of increasing investment in R&D to meet this challenge, the rate of growth in U.S. industrial R&D spending slowed considerably during the late 1980s (according to National Science Foundation data). Although there has been extensive coverage of this issue, no one to my knowledge has attempted to identify and rank the crucial factors responsible for the deceleration of R&D spending and gradual erosion in U.S. technology leadership.

The enclosed questionnaire was developed as a quick, painless way of gathering your opinions on this important issue. I urge you to take a few minutes to respond by ranking the listed factors in Part A and/or by adding others you feel may be more important. In addition, in Part B you have an opportunity to provide your recommendations on how the problem could best be tackled by those of us in industry and/or by government policymakers.

IRI has agreed to share the information from this survey with the National Science Board's (NSB) Committee on Industrial Support for R&D which, in conjunction with Commerce Department officials, has been exploring this issue. The NSB Committee will include the results of this survey and issue recommendations for NSF, other executive agencies, Congress, and the private sector in its final report on this subject. The Committee's Co-chairmen, Dr. Roland Schmitt and Dr. Arden Bement, are looking forward to having your input before the recommendations are finalized. Therefore, it is important that you return your questionnaire as soon as possible, but no later than July 15th.

Your cooperation on this project is important for IRI and the NSB to obtain a thorough understanding of the factors behind the erosion in U.S. technology leadership. Thank you in advance for your response.

Sincerely,

Wayne G. Burwell
President
Industrial Research
Institute

Enclosure

POTENTIAL CAUSES FOR THE EROSION IN U.S. TECHNOLOGY LEADERSHIP

The purpose of this survey is to identify the most important factors responsible for the erosion in technology leadership of U.S. industry. We would greatly appreciate your contributing to this project by

1. ranking the 5 major factors in Part A, using #1 for the factor you believe is most important (You may include others you feel are important that may have been omitted from this list.) Please rank them:

   _____ General management practices
   _____ Technology management practices
   _____ External financial pressures
   _____ Federal technology policy
   _____ Changing global technological environment
   _____ Other

2. ranking the items (using the blanks next to the items) under each of the 5 categories (Please use the "other" category, if necessary.)

3. commenting on the implications and consequences of continued erosion in U.S. technological leadership and listing your recommendations to improve the situation in Part B

4. identifying the industry classification(s) and domestic employment size-group of your company in Part C.

PART A

I. GENERAL MANAGEMENT PRACTICES

_____ failure and/or inability to integrate technology into business strategy

_____ management by the numbers rather than by strategic vision

_____ short time horizons

_____ high rates of executive turnover

_____ executive talent reward structure

_____ corporate executives' lack of scientific and technical insight and lack of experience in the management of science and technology

_____ other ______________________________

II. TECHNOLOGY MANAGEMENT PRACTICES

______ weakness in process technology

______ relative slowness in product development and commercialization

______ failure to integrate R&D and manufacturing

______ failure to integrate design and manufacturing

______ failure to integrate R&D and marketing

______ "big hit" mentality instead of focused, incremental development

______ high performance/high cost mentality

______ bias toward internal development

______ reluctance to commit significant resources to cooperative research for acquiring new technology

______ reluctance to invest in new enabling technologies because the R&D may be too expensive, long-term, multi-industry, and interdisciplinary

______ other ____

III. EXTERNAL FINANCIAL PRESSURES

______ growing dominance of institutional investors in equity markets and their demand for short term returns on their investments

______ investment of "patient" capital inhibited by statutory separation of the managements of industrial and financial corporations (Glass-Steagal Act)

______ pressures to reduce debt accrued through leveraged buy-outs and hostile takeovers

______ growing costs of compliance with environmental, OSHA, and other federal and state regulations that compete with and displace R&D investment

______ high cost of capital

______ high cost of U.S. labor relative to that of other countries

______ other ____

IV. FEDERAL TECHNOLOGY POLICY

______ lengthy, ineffective enforcement of federal laws against patent infringement and dumping

______ hands-off attitudes of government officials toward joint government-industry investments in emerging or endangered technologies and/or lack of sufficient funding for newly created mechanisms, e.g. the National Institute of Standards and Technology's Advanced Technology Program

______ too much investment in defense, too little investment in civilian R&D activities

______ lack of long-term strategies for expanding the economy (and tax revenues) through technological competitiveness

______ inability to support emerging technology areas that cut across government agencies

______ too little attention to the training of future scientists and engineers

______ too little attention to pre-college education

______ other ____

V. CHANGING GLOBAL TECHNOLOGICAL ENVIRONMENT

______ increasing number of skilled workers, including scientists and engineers, in other countries

______ intensifying efforts of foreign companies to derive income from the licensing of intellectual properties

______ shifts from leadership to fast-follower technology development strategies

______ declining lead times and faster product turnover cycles

______ fragmented structure of some U.S. industries (e.g., semiconductor equipment manufacturing) not conducive to efficient and effective R&D and its commercialization

______ growing difficulty of controlling enough technological competitive advantage to sustain an entry barrier against competing companies around the world

______ other ____

PART B

IMPLICATIONS AND CONSEQUENCES

Please comment on what you think may be the implications and consequences of continued erosion in U.S. technological leadership and prioritize some specific recommendations (say, 4-6) to improve the situation. If you need more space, please attach an additional sheet.

Please comment:

Please list your recommendations in order of importance:

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