United States General Accounting Office

GAO

Report to the Honorable
Lloyd Bentsen, U.S. Senate

September 1992

HIGH-TECHNOLOGY COMPETITIVENESS

Trends in U.S. and Foreign Performance

GAO/NSIAD-92-236

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-248844

September 16, 1992

The Honorable Lloyd Bentsen
United States Senate

Dear Senator Bentsen:

As you requested, we are providing information on U.S. competitiveness in high-technology areas, including assessments of trends in the U.S. position over the past decade, particularly relative to Japan.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to the Secretary of Commerce, interested congressional committees, and individuals in government agencies and private organizations who provided us with information. Copies will be made available to others on request.

Please contact me on (202) 275-4812 if you or your staff have any questions concerning this report. The major contributors to the report are listed in appendix II.

Sincerely yours,

Allan I. Mendelowitz

Allan I. Mendelowitz, Director
International Trade and Finance Issues

Executive Summary

Purpose

Debates concerning appropriate government policy in areas ranging from trade to education increasingly reflect a concern with the ability of U.S. producers to compete successfully in global markets. This concern is particularly great with regard to products embodying high levels of technology, since strong performance in those areas has been linked to increases in overall economic performance and growth.

Senator Lloyd Bentsen asked GAO to assess U.S. competitiveness in high-technology areas, considering, in particular, trends in U.S. performance over the last decade and comparisons with Japan. To do so, GAO considered several basic questions. First, what is the significance of high-technology performance, and how well can it be measured? Second, what do measures of overall U.S. performance in high-technology areas suggest? And third, for 11 particular areas suggested by Senator Bentsen, what has been the relative performance of U.S. producers and U.S. research efforts over the past decade?

Background

Interest in the competitiveness of the U.S. economy has grown steadily over the past 20 years, as the preeminent economic position of the United States has been eroded and as particular industries have come under intense competitive pressure from foreign firms. At the national level, the term "competitiveness" refers to the ability of a nation to achieve overall levels of productivity that can sustain a rising standard of living in a complex world economy. At the industry or company level, it reflects the ability of particular firms to produce products that can meet the tests of international markets while providing an adequate return to the resources they employ.

Much of the recent discussion about U.S. competitiveness has focused on international performance comparisons in the production of goods considered to embody high levels of technology and in the development of underlying technologies, reflecting the belief that relatively greater activity in research and development (R&D)-intensive sectors has a positive impact on overall productivity and economic growth.

Results in Brief

High-technology performance encompasses a wide spectrum of activity, from basic research to performance in established markets. Because no single measure reflects that whole spectrum, national aggregate high-tech assessments have focused on several indicators of high-technology activity and performance, such as trade balances in high-tech products, R&D spending, patents, and scientific publications.

Although some aggregate measures of high-technology activity indicate a declining U.S. position, especially relative to Japan, the evidence is uneven across measures. For example, the U.S. trade balance in high-technology products, which reflects performance in existing markets, declined from 1980 through 1986, according to one measure, with an upturn in the late 1980s as the dollar's value fell. An alternative measure shows a fluctuating U.S. high-technology trade surplus for the decade. U.S. R&D expenditures were about 5 times the level of R&D expenditures in Japan in 1970 but well under 3 times the Japanese level in 1988. Measures of research output, such as patents and scientific articles, show evidence of strong Japanese gains, although articles authored by U.S. researchers continue to far outnumber those of Japanese researchers.

These aggregate measures of high-technology performance have significant limitations. For example, high-technology trade statistics reflect only the location of manufacture and not ownership of resources. Observed differences across countries in patenting may reflect measurement differences as well as fundamental patterns, and subjective assessments can vary according to the experts consulted.

The 11 particular industries and technologies that GAO examined—pharmaceuticals, civilian aircraft, telecommunications equipment, fiber optics, semiconductors, semiconductor equipment and materials, robotics, flexible manufacturing systems, supercomputers, advanced materials, and consumer electronics—exhibited a range of performance trends for U.S. firms, but most exhibited some rise over the 1980s in the position of Japan relative to the United States. While these selected industries and technologies do not necessarily constitute a bellwether for the U.S. economy, they do represent important sectors with likely impacts on overall economic performance.

For many areas, clear statements of trends are difficult due to variations in performance within the industry or technology. GAO's analysis showed that for some industries in which the U.S. position has eroded substantially, the decline has been strongest in the less technologically sophisticated industry segments. For several areas examined, the increasing importance of multinational firms and international cooperative agreements complicates assessment of competitive position across countries.

GAO's Analysis

Aggregate Measures Provide Insights Into Trends but Have Significant Limitations

Some measures of trade activity in high-technology products show U.S. declines, but measures of high-tech trade vary according to the mix of products included. Department of Commerce estimates of the U.S. trade balance in high-technology products for 1978-88 show an increasing U.S. trade surplus for high-technology products from 1978 through 1982, followed by a sharp decline resulting in a first-time deficit in 1986; this balance improved in 1987-88 as the dollar's value declined. An alternative measure of U.S. high-technology trade balances, available for 1982-90 and including more narrowly defined products, shows a surplus fluctuating through the mid-1980s and increasing noticeably toward the end of the decade. And the U.S. share of the world's high-technology exports declined during 1966-86 while the Japanese share increased.

Japan's R&D spending relative to its gross national product has increased over several decades to a level similar to the U.S. ratio of R&D spending to gross national product. Absolute R&D spending is higher in the United States with its larger economy, but when defense spending is subtracted from the totals, the U.S. advantage is substantially reduced, a fact some observers believe to be increasingly important. In Japan, industry is the main source of R&D funds; R&D funding in the United States is divided almost equally between government and industry sources. One survey comparing industrial R&D spending in the United States and Japan found industrial R&D in the United States to be much more oriented toward developing products, as contrasted with processes and, for both products and processes, it found U.S. firms' R&D to be more heavily focused on developing entirely new ones.

The Japanese share of U.S. patents increased from 4 to 21 percent during 1970-89, with analysis of citations per patent providing some evidence that these patents are significant as well as numerous. Data on royalties and license fee receipts show that the United States remains a strong exporter of technology and that both the value of U.S. technology exports to and imports from Japan increased during the 1980s, with a rise in the net outflow to Japan of U.S. technology. The number of scientific publications by Japanese researchers increased over the 1980s substantially faster than the world average, but the number of articles by U.S. researchers, across all fields, was approximately 6 times the number by Japanese researchers for the decade. And several recent studies of trends in the U.S. position in specific technologies, relying primarily on subjective assessments by industry experts, have reported strong relative gains by Japanese researchers.

These aggregate indicators have significant limitations. Measures of high-tech trade activity, in addition to being sensitive to the mix of products included, have limitations characteristic of trade measures in general. Specifically, they do not capture a country's strength in its domestic markets; they reflect only the location of manufacture and not the ownership of resources; and they reflect not only the performance characteristics—such as quality and price—of particular goods, but also macroeconomic factors such as national savings rates and government and private spending.

Patents are not of equal significance, and there may be systematic differences in patent importance across countries and classes of goods. With patent citation analysis, a patent's significance is assessed according to the frequency of its citation in subsequent patent applications. However, such analysis adjusts patent counts imperfectly and does not provide a clear picture of the relative commercial importance of a country's innovation efforts. While the U.S. position as a strong exporter of technology, measured by royalty and license fee receipts, is evidence of U.S. technological strength, that position can also be viewed as an indicator of the failure of U.S. industry to fully exploit its technological assets. And differences among several recent studies that use subjective assessments in ranking countries' standing in various technology categories illustrate that such assessments can vary according to the experts consulted.

Industry Trends Display Wide Range of Competitive Positions

The 11 specific industries and technologies Senator Bentsen asked GAO to examine display a wide range of trends in competitive position, with most of the industries and technologies exhibiting some decline in the U.S. leadership position over the 1980s. One exception may be pharmaceuticals, in which U.S. firms maintained their strong position over the decade. The extent to which gaps have been narrowed in technology development and supply of goods varies widely, however. In civilian aircraft, for example, the United States maintained its position as dominant world supplier throughout the decade, although the market share of Europe's Airbus increased. And the United States maintained its world leadership position in supercomputing technology, as Japanese supercomputer firms, although weak in some areas, saw their competitiveness and market position improve. In contrast, the last of the large-volume U.S. robot producers was acquired by a foreign firm in 1990, and U.S.-based firms' share of the semiconductor materials and equipment markets fell steadily over the 1980s.

For some industries, such as telecommunications equipment, the erosion in the market position of U.S. producers has been greatest in the less technologically sophisticated segments of the industry. In contrast, in some very technology-intensive areas, such as supercomputers, a strong U.S. position is being challenged by Japanese competitors largely on technological terms. Evaluating emerging performance trends in specific areas is most difficult for rapidly evolving goods and emerging technologies, where trade and market share data may be poor indicators of future position. Even for products for which such measures are conceptually useful, the limited availability of reliable data makes assessments difficult.

For some of the industries examined, the presence of multinational firms and collaborative international ventures complicates assessments of competitiveness and illustrates that assessments of U.S. competitiveness can differ significantly depending on how "U.S. performance" is defined. Siecor Corporation in fiber optics, a U.S./German joint venture, and GMF in robotics, a U.S./Japanese joint venture, are examples of joint ventures that are major players in their respective world markets.

Recommendations

This report contains no recommendations.

Agency Comments

Because this report does not evaluate the programs or performance of any particular federal agencies, GAO did not seek agency comments on it. Several economists from academic and other research institutions reviewed a draft of the report. Their comments have been incorporated where appropriate.

Contents

Tables

Figures

Abbreviations

AT&T	The American Telephone and Telegraph Company
ATP	advanced technology product
DOD	Department of Defense
DRAM	dynamic random access memory
GAO	General Accounting Office
GNP	gross national product
ITA	International Trade Administration
NIC	newly industrialized country
R&D	research and development
U.K.	United Kingdom

Introduction

"Competitiveness" is a term that has appeared in much of the past decade's debate over appropriate government policy in a variety of areas. At the national level, competitiveness refers to the ability of a nation to achieve overall levels of productivity that can sustain a rising standard of living in a complex world economy. At the industry or company level, it refers to the ability of particular firms to produce and sell products that can meet the tests of international markets while providing an adequate return to the resources employed in their production. The performance of U.S. high-technology industries has become a focus of the debate on competitiveness, reflecting the belief that superior performance in the development and production of goods embodying high levels of technology has been and will continue to be central to U.S. economic growth and rising living standards.

The Relative Economic Position of the United States

Comparisons of economic performance across countries are generally based on macroeconomic indicators, such as levels and growth rates of gross national product (GNP) and productivity, or trends in international trade activity. According to such indicators, there has been a substantial narrowing of the gaps between the national performance of the United States and other major industrial economies. For example, in the 1950s, output per worker in the United States was roughly 2 times that of the major European countries and nearly 5 times that of Japan. By 1990, per capita output in France, West Germany, and Japan were within 20 percent of U.S. levels. This change in relative performance reflects the fact that those economies averaged rates of growth over that period that were substantially higher than that of the United States.

Productivity measures show similar trends. U.S. labor productivity, defined as output per hour worked, has increased at an average annual rate of 1.4 percent since 1950, while annual labor productivity growth has averaged 3.8 percent for Germany and 5.9 percent for Japan. Although the 1980s have seen some productivity increases for the United States, they are relatively modest and do not offset the trends of the preceding several decades.

A third national economic indicator whose trend has generated concern, although over a more recent period, is the U.S. balance in international trade. In its current account, the broadest measure of international trade, the United States generally ran small surpluses, with occasional small deficits, until 1982, when the measure began to show a continuing trade deficit, which peaked at $162 billion in 1987. Drawing conclusions and policy implications from aggregate national statistics must be done with caution; the statistics are of varying quality, and trends in macroeconomic statistics reflect many factors. For example, the dramatic fall in the U.S. overall trade balance from 1981 through 1987 and its subsequent recovery in the last part of the decade is highly correlated with changes in the value of the U.S. dollar over that period. And the role of market access in U.S.-Japan trade in particular continues to be debated. Also, measuring the change in some variables, such as the quality of U.S.-produced goods, in affecting trends in trade statistics is quite complicated.

Some convergence over recent decades in economic performance across countries is not surprising. The United States entered the post-World War II period at a strong advantage, with Europe and Japan heavily damaged by the war. The "catch-up" explanation of observed growth rate differentials is consistent with the observation that the growth rates of the Japanese and European economies, although still higher than that of the United States, were considerably lower in the 1980s than in the 2 preceding decades.

However, some observers have argued that the "recovery was inevitable" proposition does not adequately explain the relative performance differences, especially the impressive performance of Japan. They point to Japan's emergence as a world class competitor in many areas and wonder whether Japan will surpass the United States as the undisputed technological leader in most parts of industry.

Concern Exists Over U.S. Performance Trends in High-Technology Areas

Discussions of U.S. competitiveness have increasingly focused on international performance comparisons in the production of goods considered to be high tech, and in the development of underlying technologies. Numerous private and government studies have reported that U.S. leadership in high-technology areas has been eroded and that Japan in particular is gaining ground in many key technologies. [1] Evidence for these conclusions include obvious measures, such as the declining share of U.S. firms in the production of certain goods, as well as more subjective indicators such as surveys of industry and technology experts regarding the rate of technology development. Reports of a diminished U.S. role in the production and development of high-technology products raises the question of why high-tech performance is important. Since economic

[1] See, for example, Emerging Technologies: A Survey of Technical and Economic Opportunities, Technology Administration, Department of Commerce (Washington, D.C.: 1990); Perspectives: Success Factors in Critical Technologies, Computer Systems Policy Project (Washington, D.C.: 1990); and Gaining New Ground: Technology Priorities for America's Future, Council on Competitiveness (Washington, D.C.: 1991).

growth can be achieved through increasing output of whatever goods a country has a relative advantage in producing, one may ask why certain industries or types of economic activity should be the focus of such concern. For example, what, if anything, makes the production of computers a more desirable activity than the production of shoes?

A common response is that although investment in physical and human capital across the full spectrum of productive activity is vital for economic growth, certain sectors offer the greatest potential for high levels of productivity and for advances in productivity. Firms that are innovative possess advantages in their products and production processes that can translate into higher returns to the inputs they employ, such as, for example, higher wages. Thus, innovative, or technology-intensive, sectors would be expected to be particularly valuable in terms of contributing to a rising national income. [2] [3]

An interesting and relevant debate concerns the extent to which it is necessary for a firm, or a nation, to undertake innovative activity itself in order to be able to gain from such activity. In other words, is it necessary to be a technological leader in order to profit from technology advances? Japan's apparent history of achieving commercial success in areas in which the basic technological advances were first made in the United States is cited as evidence of the importance of this question.

The answer depends on how quickly and freely firms can take advantage of the technological advances of others. If there are barriers or delays, then those firms or nations that acquire capabilities first are, other factors being equal, at a competitive advantage. That there are at least some barriers to the spread of technological advances is clear. Patents, for example, provide a period of exclusive marketing for the developers of many new products and processes. In fact, formal barriers such as patents may not be the most important blocks to the spread of technological advances. For example, a survey of R&D executives revealed that the lead time that being

[2]A full analysis of the net benefits of innovation and of policies affecting innovation must recognize that there are several beneficiaries. These include the innovating firms themselves, competing firms and firms in other industries that can appropriate some of the technological gains, and consumers of goods whose cost or quality has been improved. The last category can include both individuals and firms, some of whom are themselves high-tech producers.

[3]The argument for maintaining significant domestic research and development (R&D) and production capabilities in various high-tech sectors is also made on national security grounds. Reliance on foreign sources of supply for current procurement and future development of critical defense items can entail unacceptable risks. This national security argument has been extended to define any dependence on foreign technology as potentially risky, even for technologies without immediate military implications.

first provides was considered to be the most important advantage of undertaking innovative activity.

To the extent that the benefits of innovative activity cannot be fully captured by the innovating firm, such activity is likely to generate valuable spillovers. That is, in many cases, other firms and even other industries can gain from the experience of an innovative firm. To the extent that these spillovers extend beyond national borders, firms worldwide will benefit. But if technological spillovers are limited in geographic reach, as they likely are to some extent, then those advantages are greater for domestic firms. [4]

Evaluation of the national economic benefits of innovative activity is becoming increasingly complicated as international collaborative ventures in high-technology areas have increased in number and in scope. Such ventures are now likely to involve R&D and product development, in addition to the more traditional production or marketing arrangements, with the possibility of significant technology transfer. Two prominent examples of such ventures are Siecor, which was formed in 1977 as a joint venture between Corning Glass and the German firm Siemens in order to develop and market fiber optic cable and has become a major supplier of fiber optic cable, and GMF, a venture between General Motors and the Japanese robotics producer, Fanuc, established in 1982, which is now the leading supplier of robots for the U.S. market.

High-Technology Performance Involves Many Activities

Despite the increasing interest in high-technology performance, the term "high technology" (or "high tech") does not have a clear and consistent definition. Assessments vary not only in terms of their conclusions, but also in terms of what are included as high-technology areas. The term "high technology" is used to refer to relatively mature industries that are characterized by high levels of research and development, such as commercial aircraft, telecommunications equipment, and pharmaceuticals and also to younger, R&D-intensive industries such as robotics and biotechnology. In addition, assessments of high-tech performance often also consider particular technology areas that may have applications across several industries, such as advanced materials and electronic components.

[4] One possible disadvantage to a lack of domestic technological capability is delay in obtaining state-of-the-art products from suppliers in other countries. GAO reported that a number of U.S. electronics producers perceived such delays with regard to purchases from Japanese semiconductor and computer suppliers. (See International Trade: U.S. Business Access to Certain Foreign State-of-the-Art Technology (GAO/NSIAD 91-278, Sept. 12, 1991).)

Some of these industries included in the high-technology category, broadly defined based on measures such as overall industry R&D efforts, contain a mix of high- and low-technology products. Telecommunications equipment serves as a good example of such a broad grouping of products, containing technologically advanced transmission systems as well as simple and inexpensive telephones.

Thus, high-technology performance encompasses a spectrum of activity, from basic scientific research to performance in established markets. Distinguishing among aspects of high-tech activity is important for more than definitional clarity. Comparisons of the approaches to success in high-tech markets favored by U.S. and Japanese producers, respectively, have pointed out differences in approach or strategy across the two countries. Historically, observers differentiated between Japan's success in adapting existing technologies to meet consumer needs, and the stronger U.S. capabilities for making the important scientific and technological advances necessary for such products. More recently, analysts have noted a greater emphasis by U.S. producers on end products with high-tech components that may be purchased as inputs—often from Japan—contrasted with a strategy more apparent in Japan of manufacturing technologically advanced core products that are components in a variety of end products. [5] It is clear that evaluation of high-technology performance requires consideration of several levels of activity, looking toward where the economic benefits are and where policies can be adjusted to encourage those benefits.

Several Factors Underlie High-Technology Performance Trends

Many studies identifying an erosion in the international position of U.S. producers of high-technology products have also cited a variety of factors underlying the decline. The broadest factors represent trends external to one economy: the increased transfer of goods and associated technologies among countries, and increases in the rate of diffusion of scientific knowledge. Country-specific factors tend to lie in three areas: macroeconomic factors, such as monetary and fiscal policies of the government and associated exchange rates and cost of capital; goals, policies, and management systems of businesses themselves; and government policies directed at particular aspects of the economy or particular industries.

[5] An exposition of the "core competency" argument is found in C.K. Prahalad and Gary Hamel, "The Core Competence of the Corporation," Harvard Business Review (May-June 1990).

The case that broad external factors have been important to technological convergence includes the argument that the free flow of world trade has eroded the advantages U.S. firms once had in serving the world's largest market. A related argument is that the internationalization of business has diminished national borders and status as factors obstructing access to technology.

Comparisons of the macroeconomic environment that U.S. firms have encountered with that facing Japanese competitors have generally concluded that Japan's macroeconomic policies have been more favorable for growth and technological development. According to a number of studies, Japanese firms faced a significantly lower cost of capital than U.S. firms through the 1970s and early 1980s, due largely to differences in governmental policies and national savings rates—i.e., the net result of individual savings and government borrowing.

Industry structure and company behavior have been cited as important determinants of a country's technological performance. Three aspects of Japanese industry have, for example, been identified as having worked together to create an atmosphere that facilitates innovation: strong competition among firms, firm structure and management, and ownership ties among Japanese businesses.

The debate over the determinants of high-technology competitiveness is perhaps liveliest with regard to the role of government policies directed at specific sectors and industries. The Japanese government's role in employing a variety of policies to assist the development of particular industries, ranging from support for R&D consortia in semiconductors to the establishment of low interest rate loans for purchasers of robots, has been viewed as key to that country's technological progress. Compared with policies in place 30 years ago, Japanese industrial policy today is less forceful. Many argue, however, that the Japanese government retains the role of a signaller of the direction of future technological development and sponsor of long-range, risky R&D projects that are not attractive to industry.

Objectives, Scope, and Methodology

Because U.S. technological leadership has been challenged in recent years, Senator Lloyd Bentsen asked us to assess trends over the past decade in the U.S. position in high-technology areas, particularly relative to Japan. Specifically, we considered three basic questions.

First, what is the significance of high-technology performance and how well can it be measured? Second, what do measures of overall U.S. performance in high-technology areas suggest? And third, for particular high-tech areas suggested by Senator Bentsen, what has been the relative performance of U.S. producers and U.S. research efforts over the past decade?

To address these objectives, we reviewed numerous completed and ongoing studies of performance in high-technology areas, including both broad and technology-specific studies. We interviewed experts in government, industry, and academic organizations, and analyzed material they provided. We obtained and analyzed data from U.S. government agencies, such as the National Science Foundation, and from international organizations, such as the Organization for Economic Cooperation and Development.

We performed our review from September 1990 through February 1992 in accordance with generally accepted government auditing standards.

Because this report does not evaluate the programs or performance of any particular federal agencies, we did not seek agency comments on it. Several economists from academic and other research institutions reviewed a draft of the report. Their comments have been incorporated where appropriate.

Measures of High-Technology Competitiveness Provide Insights but Have Limitations

Several measures can provide insight into high-technology performance trends across countries and across the spectrum of high-tech activity. For example, high-technology trade aggregates reflect performance in existing markets; breakdowns by nationality of recipients of U.S. patents are indicators of trends in innovation; and analysis of authorship of articles in scientific journals can reveal national strengths in basic research. Each of these measures has significant limitations, and they should be viewed as only rough indicators of trends in technological standing. Supplementing these aggregate measures are several recent studies of national trends in technology development that have been based on the subjective assessments of science and technology experts in a number of fields.

These aggregate measures of high-technology performance and broad technology surveys provide some evidence of a decline in the U.S. leadership position in developing and marketing technology-intensive products, particularly relative to Japan. This evidence is not conclusive across all areas of high-technology activity. For example, one measure of the U.S. trade balance in high-technology products showed a decline between 1982 and 1986, followed by a strong upturn attributable in part to the falling dollar. The Japanese share of U.S. patents has increased steadily over the past 20 years, and limited indicators of relative position in basic research show continued overall U.S. strength, with some pockets of strong Japanese performance. Subjective assessments of technology development report strong relative gains in recent years by Japanese researchers for many technology areas.

Trade Performance as a Competitiveness Measure Has Limitations

Current concern over the U.S. trade position extends beyond growing trade deficits to the question of technological leadership. Several measures of the activity of U.S. firms in the trade of high-technology products have been developed, and they show varying trends. Measures of high-technology trade are sensitive to the definitions of high-tech products; the more disaggregated, or finer, definitions tend to produce a more favorable picture of trends in the U.S. position.

Although measures of trade in aggregates of high-technology products are important as the only indicators that present a picture bigger than that of a particular industry, they have important limitations, which are characteristic of trade measures as an indicator of competitiveness in general. Chief among these limitations is that trade patterns reflect not only the performance characteristics—such as quality and price—of particular goods, but also reflect macroeconomic factors.

These macroeconomic factors that influence trade performance are basic ones: national savings rates, government and private spending, inflation, and interest rates. Their effect on trade balances is seen most clearly in the swings in the value of the dollar, determined largely by those basic factors, which occurred in the 1980s. When the dollar rose against other major currencies in the first half of the 1980s, it sharply raised the prices of U.S. goods relative to foreign goods, encouraging imports and discouraging exports. Some of this effect was reversed when the dollar fell again after 1985.

Thus, the influence of performance characteristics of particular industries and firms—product quality and production efficiency, for example—on trade patterns, can only be seen in conjunction with the effect of macroeconomic factors. While it may be difficult to isolate their effect, analysis of trade patterns, in particular for high-technology products, does yield answers to several questions. For example, is there a uniform performance trend across high-technology sectors, or are there important variations? And does the trade performance of U.S. high-tech industries differ significantly from that of other sectors of the economy? These questions are addressed in the following sections.

A second limitation of trends in high-technology trade as a performance indicator is that trade statistics tend to reflect only location of production and not ownership of resources. For industries in which the role of multinationals is important—where, for example, goods are assembled abroad but important technology is developed and controlled domestically—production-based trade measures can misrepresent some aspects of competitiveness. Some survey data have allowed limited examination of this issue, which is discussed later in this chapter.

Evidence on U.S. High-Technology Trade Balance Is Mixed

Evidence on trends in the U.S. trade balance in high-technology products is mixed, with measures of high-tech trade showing strong sensitivity to the mix of products included. One effort at tracking high-tech trade has been that of the International Trade Administration (ITA) of the Department of Commerce, which published estimates of the U.S. trade balance in high-technology products between 1978 and 1988. Bureau of the Census researchers have used an alternative high-tech trade measure to estimate the U.S. high-tech trade balance for 1982-90.

Table 2.1 shows the U.S. trade balance in high-technology products, published by ITA for 1978-88. ITA's aggregate measure shows an increasing

U.S. trade surplus for high-technology products from 1978 through 1982, followed by a sharp decline resulting in a first-time deficit in 1986. This drop was followed by an upturn for 1987 and 1988. An ITA official indicated that the measure would likely reflect a continued surplus in the 1989-90 period.[1]

Table 2.1: U.S. High-Technology Trade, ITA's Measure, 1978-88

Dollars in millions

Years	Exports	Imports	Trade balance
1978	$34,839	$19,829	$15,010
1979	43,524	22,251	21,273
1980	54,712	27,385	27,327
1981	60,390	33,025	27,365
1982	58,112	33,653	24,459
1983	60,158	40,257	19,901
1984	65,510	57,779	7,731
1985	68,425	63,090	5,336
1986	72,517	73,261	-744
1987	84,071	84,417	2,654
1988	104,280	96,188	8,092

Source: International Trade Administration, U.S. Department of Commerce.

Analysis of trade balances for advanced technology products (ATP) by Census researchers, available for 1982-90, shows a somewhat different pattern, with a surplus fluctuating through the mid-1980s and increasing noticeably toward the end of the decade. This pattern is shown in table 2.2. While ITA's measure and the ATP measure were very close in 1982, they quickly diverged and by 1985 differed by approximately $20 billion. These patterns are shown graphically in figure 2.1.

[1]According to an ITA official, ITA is not currently calculating these trade balances, due to lack of an adequate concordance for linking trade data collected under the new Harmonized System with data collected under the old import and export categories.

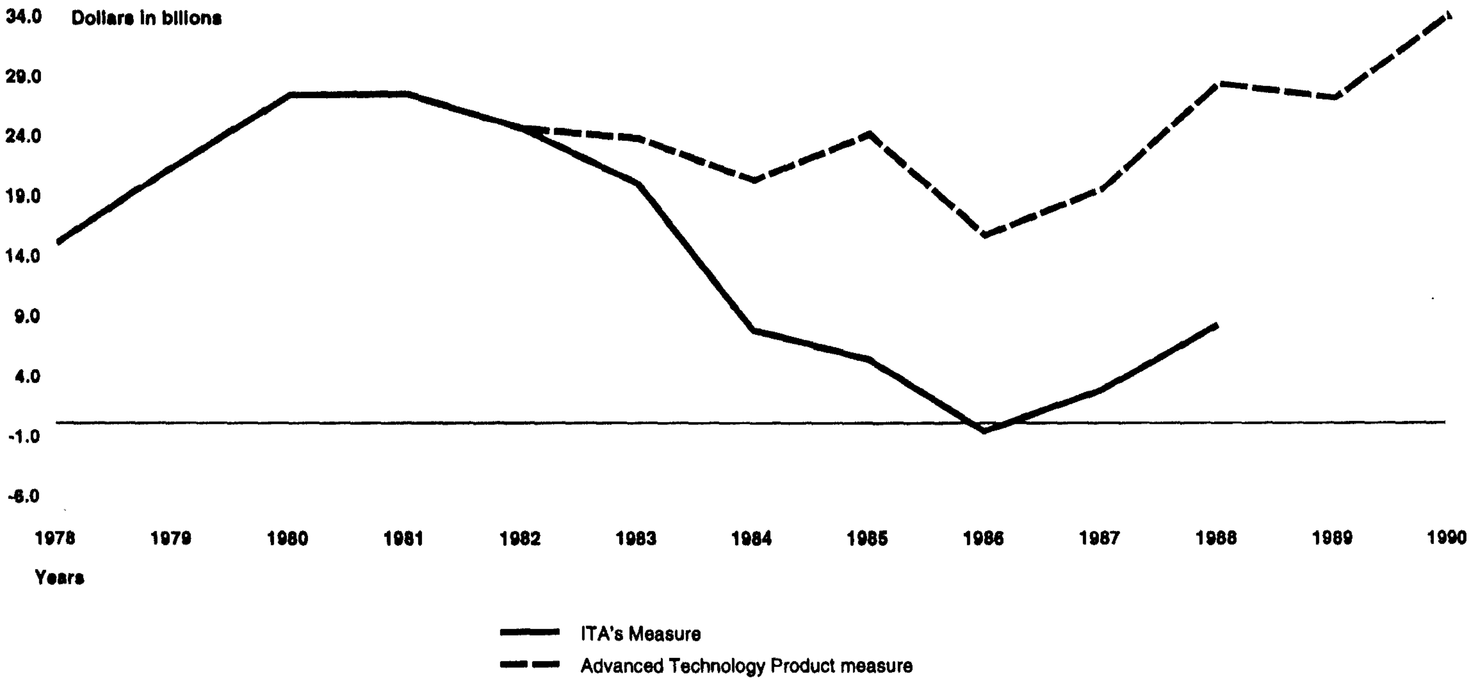
Table 2.2: U.S. High-Technology Trade, Advanced Technology Product Measure, 1982-90

Dollars in millions

Years	Exports	Imports	Trade balance
1982	$39,718	$15,170	$24,458
1983	42,536	18,890	23,646
1984	46,868	26,648	20,220
1985	51,497	27,552	23,945
1986	53,501	37,861	15,640
1987	62,087	42,662	19,425
1988	77,956	49,711	27,241
1989	83,483	56,435	27,047
1990	93,377	59,296	34,081

Source: Bureau of the Census, U.S. Department of Commerce.

Figure 2.1: U.S. High-Technology Trade, ITA's Measure Compared to ATP Measure



Sources: U.S. Department of Commerce, International Trade Administration and Bureau of the Census.

The ITA and ATP measures of high-technology trade include different products, as a result of differences in their methods of classifying products as high tech. The ITA measure, based on industry R&D intensity, is broader and encompasses products that are not technologically sophisticated. The high-technology categories tracked by the ATP measure are more subjectively determined and also more narrowly defined.[2] Both measures may be useful, if imperfect, indicators of trends in high-tech trade—ITA's measure for tracking groupings of products that have in the aggregate a strong R&D component and will contain the bulk of high-tech products with some consistency, and the ATP measure for tracking trends in traded products embodying leading-edge technologies.

Evidence on Trade Balance Trends, for Groupings of Products, Varies Widely

With regard to the question of uniformity of trade performance across categories of high-technology products, both the ITA and ATP measures display wide variations among product groupings or industries in terms of the trade trends over the past decade. As the measures differ in their estimates of aggregate high-technology trade balances, they also differ in the trends they report for particular product groupings. However, they exhibit some important similarities. The ITA measure shows a large fall in the U.S. trade balance in the "communications equipment and electronic components" category, and a significant rise in "aircraft and parts." And according to the ATP measure, there were large falls over the 1982-89 period in the U.S. trade balance in the "optoelectronics," "computers and telecommunications," and "electronics" categories, and large gains in "material design" and "aerospace."

[2]The ITA measure begins by defining industries as high tech using the ratio of applied R&D expenditures to sales of domestic producers as a proxy for the level of technology embodied in the product. This measure is based on both the direct R&D expenditures of the industry and the R&D efforts embodied in other goods that industry uses as inputs, as determined by an input-output table of the U.S. economy. The industries tracked by ITA are then those with the highest ratios of direct and indirect R&D to sales.

In contrast, in devising the ATP measure, Census Bureau analysts develop a list of "leading edge" technologies and then examine lists of individual products to determine which ones contain a significant amount of one or more of those technologies. Those products are then classified as "advanced technology products."

Trends in World Export Shares of High-Technology Goods Can Be Tracked

An alternative approach to analyzing trends in U.S. trade in high-technology products focuses on the U.S. share of total world exports of such products. This analysis is useful for considering how high-tech trade performance has compared to the trade performance of other sectors of the U.S. economy. Analysis of world export data shows that for the world as a whole, trade in manufactured goods has been shifting out of low-tech goods into goods with higher technology components. [3] (This analysis is based on Organization for Economic Coorperation and Development classifications of products into low-, medium-, and high-technology categories, using an R&D intensity criterion similar to that of the ITA measure.) This trend in the distribution of traded goods is consistent with, but more pronounced than, the trend in the distribution of world output toward high-technology goods.

This research shows that both the United States and Japan have their highest export shares for manufactured goods in high-technology sectors and their lowest shares in low-technology ones. From 1966 to 1986, the U.S. share of world high-technology exports of manufactured goods dropped from about 24 percent to about 19 percent, a smaller decline than that for U.S. export shares overall. Germany's share of world high-technology manufactures exports also dropped during 1966-86, while the shares of Japan and the newly industrialized countries (NIC) in Asia—South Korea, Hong Kong, Singapore, and Taiwan—increased. [4] The trends for high-, medium-, and low-technology exports are depicted, respectively, in tables 2.3, 2.4, and 2.5.

[3]See Irving B. Kravis and Robert E. Lipsey, "Technological Characteristics of Industries and the Competitiveness of the U.S. and its Multinational Firms," National Bureau of Economic Research #2933; and "Sources of Competitiveness of the U.S. and of its Multinational Firms," The Review of Economics and Statistics, 74,2 (May 1992), pp. 193-201.

[4]Kravis and Lipsey point out that the data somewhat overstate the high-tech shares for Japan and the Asian NICs because the data base includes TV and radio equipment and some transport equipment in the high-tech category. These items should ideally have been separated.

Table 2.3: U.S., German, Japanese, and Asian NICs' Share of World High-Technology Exports for 5 Selected Years

Percent

Country	1966	1977	1982	1985	1986
United States	23.9	18.8	22.0	20.8	18.7
Japan	12.4	19.8	19.0	21.6	21.6
Germany	15.4	14.8	12.9	11.0	12.2
Asian NICs	0.9	5.3	7.4	9.6	9.2

Note: World exports are defined as exports to developed market economies.

Source: Kravis and Lipsey, "Technological Characteristics of Industries and the Competitiveness of the U.S. and its Multinational Firms."

Table 2.4: U.S., German, Japanese, and Asian NICs' Share of World Medium-Technology Exports for 5 Selected Years

Percent

Country	1966	1977	1982	1985	1986
United States	20.9	15.6	15.9	14.3	11.8
Japan	4.5	10.4	12.8	15.2	15.7
Germany	20.4	21.0	19.1	18.1	20.4
Asian NICs	0.4	1.1	2.3	2.6	2.7

Note: World exports are defined as exports to developed market economies.

Source: Kravis and Lipsey, "Technological Characteristics of Industries and the Competitiveness of the U.S. and its Multinational Firms."

Table 2.5: U.S. German, Japanese, and Asian NICs' Share of World Low-Technology Exports for 5 Selected Years

Percent

Country	1966	1977	1982	1985	1986
United States	11.5	8.3	9.1	7.5	7.0
Japan	7.8	7.7	7.7	6.9	6.0
Germany	8.4	10.5	10.2	10.1	11.1
Asian NICs	2.7	6.8	9.1	10.1	10.6

Note: World exports are defined as exports to developed market economies.

Source: Kravis and Lipsey, "Technological Characteristics of Industries and the Competitiveness of the U.S. and its Multinational Firms."

A related finding is the contrast between the movement of U.S. shares and those of U.S.-owned multinationals. Using world export data in conjunction with information from two Commerce surveys on U.S. investment abroad, researchers found that while the U.S. share of world exports dropped from 17 percent in 1966 to about 12 percent in 1986-88, the U.S. multinationals' share of world exports, also 17 percent in 1966, was between 15 and 16 percent in 1986-88. This differential is strongest for the medium- and high-technology groups, with the implication that technology is a particularly important element of the competitiveness of U.S. multinationals.

Assessing Research and Innovation Strength Across Countries Is Difficult

Since high-technology performance is a function of many activities, some substantially removed from the marketing of existing products, evaluations of trends in performance look beyond trade and market share data to comparisons of innovative activity. These comparisons are of necessity made with imprecise measures, since innovative activity cannot be perfectly quantified. In this section, we review evidence from several measures of innovation—R&D spending, patent activity, technology trade, and scientific articles publication—as well as recent surveys of industry experts. These measures indicate that the technological gap between the United States and Japan has narrowed in recent years, with Japan exhibiting a leadership position in some areas.

R&D Spending Comparisons

Throughout the 1960s, the United States maintained a substantial advantage over its competitor nations in terms of the proportion of national output invested in R&D efforts. This lead was largely eroded during the 1970s, and the 1980s saw similar overall R&D efforts by the United States, France, West Germany, and Japan. The numbers in table 2.6 illustrate these trends. Because of the greater size of the U.S. economy, its absolute R&D spending has remained higher.

In comparisons of U.S. aggregate R&D spending with that of other nations, two characteristics of that spending have been identified as important to the ultimate value of R&D efforts to overall economic growth: (1) the distribution of R&D in terms of defense and nondefense expenditures and (2) the distribution of the R&D expenditures along the R&D spectrum from basic to applied research efforts, and the related distribution of funding between government and industry sources.

Table 2.6: Total U.S., French, West German, and Japanese R&D Spending, 1961-88

Constant 1982 dollars in billions

	United States		France		West Germany		Japan	
Year	Amt	% of GNP	Amt	% of GNP	Amt	% of GNP	Amt	% of GNP
1961	$45.8	$2.7	$3.2	1.4%	NA	NA	$3.9	1.4%
1962	48.2	2.7	3.6	1.5	$4.2	1.2%	4.4	1.5
1963	52.7	2.8	4.0	1.6	4.9	1.4	4.9	1.5
1964	57.3	2.9	5.0	1.8	5.8	1.6	5.5	1.5
1965	59.3	2.8	5.8	2.0	6.7	1.7	6.1	1.6
1966	62.5	2.8	6.3	2.1	7.3	1.8	6.6	1.5
1967	64.4	2.8	6.8	2.2	7.9	2.0	7.6	1.6
1968	65.2	2.8	7.0	2.1	8.4	2.0	9.0	1.7
1969	64.4	2.7	7.1	2.0	8.3	1.8	10.5	1.7
1970	62.2	2.6	7.1	1.9	9.9	2.1	12.4	1.9
1971	60.1	2.4	7.4	1.9	10.9	2.2	13.3	1.9
1972	61.3	2.3	7.7	1.9	11.4	2.2	14.7	1.9
1973	62.0	2.3	7.7	1.8	11.3	2.1	16.1	2.0
1974	60.9	2.2	8.1	1.8	11.5	2.1	16.4	2.0
1975	59.4	2.2	8.1	1.8	11.9	2.2	16.7	2.0
1976	61.9	2.2	8.4	1.8	12.1	2.1	17.3	2.0
1977	63.6	2.1	8.6	1.8	12.4	2.1	18.0	2.0
1978	66.6	2.1	8.9	1.8	13.3	2.2	19.1	2.0
1979	69.9	2.2	9.4	1.8	15.0	2.4	21.0	2.1
1980	73.0	2.3	9.8	1.8	15.3	2.4	23.1	2.2
1981	76.5	2.4	10.8	2.0	15.9	2.5	25.5	2.3
1982	80.0	2.5	11.7	2.1	16.5	2.6	27.4	2.4
1983	85.8	2.6	12.0	2.1	16.0	2.5	29.9	2.6
1984	93.9	2.7	12.7	2.2	17.0	2.6	32.4	2.6
1985	102.5	2.8	13.1	2.3	18.8	2.8	36.1	2.8
1986	105.3	2.8	13.4	2.2	19.3	2.8	36.6	2.8
1987	108.4	2.8	13.9	2.3	20.2	2.9	39.2	2.8
1988	111.5	2.8	14.5	2.3	20.8	2.9	42.3	2.9

Note: NA denotes not available.

Source: National Science Foundation.

As Table 2.7 shows, the United States enjoys a considerably smaller advantage over its major competitors in terms of nondefense R&D spending levels and lags substantially behind Japan and Germany in terms of the portion of GNP devoted to R&D spending for nonmilitary purposes. In 1985, slightly less than 1 percent of total Japanese R&D expenditures was for military purposes, while the corresponding figure for the United States was

30 percent.[5] Observers have argued that the strong military component of U.S. R&D efforts has recently been generating fewer benefits to civilian markets. In fact, notes one analyst, the technological spillovers of R&D may now be running from civilian to military applications instead of in the opposite, more traditionally asserted, direction. He cites as an example the increasing focus of semiconductor and computer technology development on civilian applications.[6]

Table 2.7: U.S., French, West German, and Japanese Nondefense R&D Spending, 1971-88

Constant 1982 dollars in billions

	United States		France		West Germany		Japan	
Year	Amt	% of GNP	Amt	% of GNP	Amt	% of GNP	Amt	% of GNP
1971	$41.8	1.6	$5.7	1.5	$10.1	2.0	$13.2	1.9
1972	42.1	1.6	6.1	1.5	10.7	2.1	14.6	1.9
1973	43.8	1.6	6.0	1.4	10.5	1.9	16.0	2.0
1974	44.2	1.6	6.5	1.4	10.7	2.0	16.3	2.0
1975	43.1	1.6	6.6	1.5	11.2	2.1	16.6	2.0
1976	45.3	1.6	6.8	1.4	11.3	2.0	17.2	2.0
1977	46.0	1.6	7.0	1.4	11.6	2.0	17.9	2.0
1978	48.8	1.6	7.1	1.4	12.5	2.1	19.1	2.0
1979	52.4	1.6	7.4	1.4	14.2	2.3	21.1	2.1
1980	55.6	1.7	7.6	1.4	14.5	2.3	23.3	2.2
1981	56.9	1.8	8.1	1.5	15.2	2.4	25.7	2.3
1982	57.9	1.8	9.0	1.6	15.8	2.5	27.5	2.4
1983	61.7	1.9	9.4	1.7	15.3	2.4	29.9	2.5
1984	66.7	1.9	9.9	1.7	16.2	2.5	32.4	2.6
1985	72.1	2.0	10.5	1.8	17.9	2.7	35.9	2.8
1986	72.9	2.0	10.7	1.8	18.4	2.7	36.4	2.8
1987	75.2	1.9	11.0	1.8	19.3	2.8	38.9	2.8
1988	78.4	1.9	11.3	1.8	19.9	2.7	42.0	2.9

Source: National Science Foundation.

[5]Japanese military forces are limited under the Japanese constitution, designed by American forces following World War II. In addition, one analyst has observed that Japanese corporations report their expenditures on defense R&D under their general R&D accounts, which would inflate the figures for civilian R&D and obscure what is spent on defense.

[6]See Richard Nelson, "What Has Happened to U.S. Technological Leadership?" Technological Competition and Interdependence, eds. Gunter Heiduk and Kozo Yamamura (Seattle: University of Washington Press, 1990).

In Japan, industry is the main source of R&D funds; in the United States, R&D funding is divided almost equally between government and industry sources. This division is attributable in part to the greater role of defense R&D, funded largely by the government, in overall R&D efforts in the United States.

In view of the popular perception that Japan's greatest market successes over the past few decades have involved successful adaptation of existing technologies for commercial uses, it is interesting to note that breakouts of R&D data by character of work show that a similar proportion of U.S. and Japanese R&D expenditure is for basic research. For example, data reported by the National Science Foundation reveal that for 1975-88, basic research expenditures as a percentage of total R&D expenditure averaged 13 percent for the United States and 14 percent for Japan. The apparent similarities in emphasis on basic R&D for the United States and Japan may reflect in part differences in the two countries in what is considered to constitute basic research, with Japanese data on basic research expenditures including some types of research that would be classified as "applied research" in the United States.

In recent years, there has been much discussion of Japan's intention to increase its investment in fundamental or basic research. According to experts on Japanese technology development efforts, Japan's announced intention results from two factors: (1) complaints from the United States that Japan has been exploiting the discoveries of other nations without bearing its share of the cost of expanding scientific knowledge and (2) increased importance to Japanese researchers of fundamental technological breakthroughs, since they have reached world class status in many fields.[7]

Increasing basic research efforts in Japan is complicated by several factors. First, the Japanese university system and thus academic R&D efforts lag behind those of the West. This lag is due in part to a lesser federal government role in R&D in Japan, and also to U.S. universities' greater access to other funding sources, including state and local governments, philanthropic organizations, and industry. Expecting Japanese industry to bear a greater basic research burden may be unrealistic. The Japanese industrial sector—like that of other countries—is unlikely to be interested in funding research that is not of a proprietary nature.

[7]See, for example, Justin Bloom, Japan as a Scientific and Technological Superpower, National Technical Information Service, U.S. Department of Commerce (Washington, D.C.: 1990), pp. 18-25.

Much has been made in the United States of the Japanese government's support of industrial R&D through direct contracts or grants and through the establishment of jointly funded government/industry projects. The Japanese government's role in the semiconductor industry is a well-known example of the latter. In the 1970s the Japanese government provided substantial support for individual firms and for consortia engaged in semiconductor R&D, culminating in the Very Large Scale Integration Project directed at developing large scale integrated circuits. Many have credited this effort as being an important element in Japan's move to a leadership position in the world semiconductor market. While such efforts may have been important in the past for particular successes of Japanese firms, their importance and number appear to have decreased.

Several observers of Japanese industry have reported a distinct trend emerging in Japan, whereby the government's support of large scale industrial R&D projects is declining in favor of an increasing support for smaller projects aimed at developing advanced technology in its early stages. According to several analysts, the most important function of the Ministry of International Trade and Industry, the government agency traditionally at the center of Japan's industrial policy, may be to use its activities—support of consortia and government labs, and publication of scientific and technological agendas for the future—to signal the direction of the country's technological and commercial future and thus reduce the risk to particular firms of undertaking certain R&D efforts.

A 1985 survey of U.S. and Japanese firms sheds some light on the distribution of company-funded R&D in the two countries. The results of the survey of 100 firms are shown in Table 2.8. They show that firms in Japan devote a slightly higher fraction of their R&D expenditures to basic research (although possible definitional differences may exist) and that Japanese firms devote about as large a percentage of their research to relatively risky and long-term projects as do American firms. Perhaps the most striking differences detected in the survey are that (1) industrial R&D in the United States is much more oriented toward developing products, as contrasted with processes, and (2) for both products and processes, U.S. firms are more heavily focused on developing entirely new ones.

Table 2.8: Composition of U.S. and Japanese R&D Expenditures, 1985

R&D expenditures devoted to:	Japan (percent)	United States (percent)
Basic research	10	8
Applied research	27	23
Products (rather than processes)	36	68
Entirely new products and processes	32	47
Projects with less than 0.5 estimated chance of success	26	28
Projects expected to last longer than 5 years	38	38

Note: These percentages are based on a survey of 100 firms in four industries in Japan and the United States. The categories are not mutually exclusive; therefore, percentages sum to more than 100.

Source: Edwin Mansfield, "Industrial R&D in Japan and the United States: A Comparative Study," American Economic Review, vol. 78, 2 (May 1988).

Comparisons of Research Outputs

As imperfect as R&D spending measures are as indicators of inputs into the innovation process, identifying reliable quantitative measures of research output, or the gains from R&D, may be even more problematic. The gains of scientific research can be particularly difficult to quantify. Ultimately, gains in the welfare of a nation's firms and its citizens are the measurable benefits of innovation. But analysts and policymakers desire more focused and immediate indicators of R&D success. Three indicators that have been used to shed some light on gains in scientific activity, and for intercountry comparisons of research outputs, are described in the following sections—trends in patenting activity, trends in the technological balance of payments, and trends in the publication of scientific articles.

Patent and Patent Citation Trends

Table 2.9 shows the number of U.S. patents granted to inventors from the United States, France, Japan, the United Kingdom (U.K.), West Germany, and all other countries combined, for selected years over the period 1971-89. The most striking feature of this table is the dramatic gain in the number of patents issued to Japanese inventors, who received 21 percent of U.S. patents granted in 1989, compared with 4 percent in 1970.

Breakdowns of U.S. patents by industry category indicate that increases in patents by Japanese companies and researchers are significant across most categories. [8]

Table 2.9: U.S. Patents Granted to Inventors for 5 Selected Years

			Foreign origin				
Year	Total patents	U.S. origin	Total	France	Japan	U.K.	W. Germany
1970	64,429	47,077	**17,352**	1,731	2,625	2,954	4,435
1975	72,000	46,715	**25,285**	2,367	6,352	3,043	6,036
1980	61,819	37,356	**24,463**	2,088	7,124	2,406	5,747
1985	71,661	39,554	**32,107**	2,400	12,746	2,495	6,665
1989	95,539	50,185	**45,354**	3,140	20,168	3,100	8,303

Source: National Science Foundation.

Patent citation analysis is a technique developed to augment patent counts as an indicator of technical invention. Because patents are not of equal significance, and because there may be systematic differences in patent importance across countries and classes of goods, analysts have sought a method for assigning relative significance to a country's patents. [9] With patent citation analysis, a patent's significance is assessed according to how often it is cited in subsequent patent applications. Although citation analysis adjusts patent counts imperfectly and does not provide a clear picture of the relative commercial importance of a country's innovation efforts, it is one indicator of whether trends in overall patent counts should be viewed as important.

One recent analysis using the patent citation approach indicates that Japan's U.S. patents are significant as well as numerous. Table 2.10 shows the citation ratios for the most highly cited U.S. patents by nationality of inventor, for 1975-88. The index is constructed according to how often a country's patents appear in the most highly cited 10 percent of patents. Numbers greater than 1.00 indicate that a country holds a higher

[8]It would be instructive to compare these trends with trends over the same period in nonresident patent activity in countries other than the United States. Although such data are not available, data published by the National Science Foundation for a shorter period, 1985-89, show the percentage of patents awarded to nonresidents fluctuating slightly for most granting countries, with few trends apparent.

[9]For example, there has been a tendency for Japanese patentees to file single-claim patents in the United States, whereas U.S. patentees average multiple claims per patent.

percentage of the most highly cited patents than would be expected, given the total number of U.S. patents it received over the period. The table indicates that Japan held 35 percent more of the most highly cited patents than would be expected, given its total number of patent holdings. The United States held 5 percent more than would be expected, and other countries held fewer.

Table 2.10: Citation Ratios for the Most Highly Cited U.S. Patents by Nationality of Inventor, 1975-88

Rank	Country	Index
1	Japan	1.35
2	United States	1.05
3	The Netherlands	0.91
4	United Kingdom	0.91
5	Belgium	0.78
6	France	0.75
7	Canada	0.74
8	West Germany	0.72
9	Switzerland	0.67
10	Italy	0.64
11	Sweden	0.63
12	Australia	0.55
13	Austria	0.55
14	Denmark	0.54
15	Soviet Union	0.24

Source: National Science Foundation.

Trends in Technological Balance of Payments

Data on international transactions in royalties and fees are sometimes used as indicators of technological standing. According to values of royalties and fees in the balance of payments, the United States remains a strong exporter of technology. In 1989, U.S. technology outflows, measured as royalty and license fee receipts, were $12.3 billion, compared to technology inflows (payments) of $2.7 billion. [10]

Japan is the largest market for U.S. technology. In 1989, U.S. royalty and license fee receipts from Japan were $2.6 billion, representing 21 percent of outflows. The same year, Japan ranked second, behind the United

[10] These figures include transactions between both affiliated and unaffiliated parties. Affiliated transactions are those between U.S. parent companies and their foreign affiliates and between U.S. affiliates and their foreign parent groups.

Kingdom, in technology exported to the United States, with royalty and license fee receipts of $490 million, 18 percent of the U.S. payment total. Recent trends in the net exports of U.S. technology to Japan, using this measure, show a rise in both the value of U.S. technology exports to and imports from Japan during 1982-89, with a corresponding rise in the net outflow to Japan of U.S. technology. [11]

The significance of this measure can be debated. On the one hand, it is evidence of U.S. technological strength. And benefits to the United States from exporting technology include increased revenues for U.S. companies and a positive impact on the balance of payments. On the other hand, royalties and license fees are generated from longstanding agreements as well as those involving newer technologies. In addition, large net outflows of technology can be viewed as evidence of the failure of U.S. industry to fully exploit its technological assets.

Trends in Publication of Scientific Articles

Assessments of the output of R&D efforts at a stage earlier than that represented by patent activity have been made by counting numbers of and references to units of output—in this case, published scientific articles. Table 2.11 shows the contribution of selected countries to world scientific literature by field for 1981. Table 2.12 shows the same information for 1986, the latest year for which the data are available. One fact is apparent: U.S. researchers clearly dominated the scientific literature for both years. Also, the greatest change in overall country shares between 1981 and 1986 is a 13-percent increase in the number of articles published by Japanese researchers.

[11] Data on payments and receipts of royalties and license fees between unaffiliated U.S. and Japanese parties show roughly similar trends.

Table 2.11: Contribution of Six Countries to World Scientific Literature by Field, 1981

Percent

Field	U.S.	U.K.	West Germany	France	USSR	Japan
Total	35.9%	8.3%	6.3%	5.0%	8.0%	6.8%
Clinical medicine	41.3	9.8	6.4	5.2	3.3	5.1
Biomedical research	39.5	8.5	6.1	5.2	5.7	6.2
Biology	37.6	9.0	4.7	3.5	2.8	6.1
Chemistry	20.0	6.6	6.6	5.9	16.7	10.9
Physics	28.7	6.4	6.7	5.9	16.8	8.2
Earth/space sciences	42.7	8.5	4.4	4.6	10.0	2.3
Engineering/ technology	40.7	8.5	7.0	3.3	7.6	9.2
Mathematics	38.2	6.1	9.0	5.6	7.6	4.3

Source: National Science Foundation.

Table 2.12: Contribution of Six Countries to World Scientific Literature by Field, 1986

Field	U.S.	U.K.	West Germany	France	USSR	Japan
Total	35.6%	8.2%	5.8%	4.9%	7.6%	7.7%
Clinical medicine	40.0	10.4	5.6	4.6	2.9	6.4
Biomedical research	38.4	8.0	5.2	5.0	8.3	7.1
Biology	38.1	9.5	4.3	3.1	2.4	6.5
Chemistry	22.2	5.7	6.9	5.6	15.1	10.7
Physics	30.3	5.6	6.9	6.5	14.7	8.6
Earth/space sciences	42.6	7.9	4.0	4.3	7.0	3.7
Engineering/ technology	37.3	7.5	7.0	3.6	5.6	12.7
Mathematics	40.3	7.5	7.9	4.7	4.6	3.4

Note: 1986 is the latest year for which these figures are available.

Source: National Science Foundation.

Evidence of Japan's increasing scientific strength is seen also in table 2.13 which shows, for the United States and Japan, publications of articles by scientific field for 1986-90 as compared with 1981-85. Trends in the world average across fields are also shown. In all fields, Japan's researchers increased their number of scientific publications, over the years shown, at a rate substantially greater than the world average. However, since the number of articles by U.S. researchers, across all fields, was approximately 6 times the number by Japanese researchers for the 10-year period, U.S. researchers maintained a substantial advantage.

Table 2.13: Percent Change in Volume of U.S. and Japanese Scientific Articles by Sector, 1981-85 Compared With 1986-90

Field	United States	Japan	World average
Engineering, technology, and applied sciences	23.2%	23.7%	18.1%
Physical, chemical, and earth sciences	18.2	31.7	15.0
Agricultural biology and environmental sciences	7.7	31.5	9.5
Clinical medicine	21.0	71.7	23.3
Life sciences	17.5	35.7	19.2

Source: Science Watch, Vol. 2,4; Vol. 2,8 (May, Sept. 1991).

In terms of the citation impact of these articles, U.S.-authored publications continue to increase in importance. According to citation analysis of scientific literature, among seven major industrial countries (the Group of Seven), the United States exhibited the greatest improvement in the citations-per-paper performance of its science papers during the 1980s. [12] Germany's increase in citation frequency was second, and Japan's third. Japan's strongest improvement over the decade in the average importance of its scientific papers was in the physical, chemical, and earth sciences; and clinical medicine showed the second greatest gains in average importance. For the United States, the strongest gain in average citation strength was also in the physical, chemical, and earth sciences category, while engineering, technology, and applied sciences lost in citation importance.

Surveys of Technology Experts Also Assess Technology Trends

Several recent studies have used subjective assessments, in some cases in conjunction with other measures, to determine the relative position of U.S. and Japanese researchers in various technology categories. These studies, carried out by governmental and other organizations, have generally concluded that the U.S. leadership position in many technologies has been eroded. Four of the best known of these studies are Commerce's 1990 Emerging Technologies; the Department of Defense's (DOD) 1991 Critical Technologies Plan; the White House Office of Science and Technology Policy's 1991 Report of the National Critical Technologies Panel; and a 1991 report, Gaining New Ground, by the privately funded Council on Competitiveness.

[12] The Group of Seven countries are major developed countries whose leaders meet annually to discuss and coordinate certain macroeconomic policies. The countries in the group are the United States, Japan, Germany, France, the United Kingdom, Italy, and Canada.

These studies are similar in their attempt to present a broad view of the relative U.S. position in developing a variety of important technologies. They overlap substantially in the technologies they consider, although there are important differences, especially in level of detail or disaggregation. Their assessments are generally similar, although they differ for some areas. Some reports, particularly Commerce's Emerging Technologies, draw broad comparisons of trends in the U.S. position in various technologies relative to other countries. The Report of the National Critical Technologies Panel, in contrast, generally describes countries' strengths in particular technology areas. The report varies across technologies in terms of the extent to which it draws clear conclusions concerning which country has the technological edge and where future technological leadership is likely to reside. DOD's Critical Technologies Plan differs from the others in its characterization of an ally's (e.g., Japan's) technological capability in terms of whether it can contribute to U.S. military capability. Some conclusions from these studies regarding particular technologies are discussed in appendix I, which addresses the U.S. position in specific high-technology areas.

Conclusions

Aggregate performance indicators, including high-technology trade measures and measures of research spending and output, as well as broad technology surveys, provide some evidence of a decline in the U.S. leadership position in developing and marketing technology-intensive products, particularly relative to Japan. This evidence is not clear-cut for all measures of high-technology activity, and some measures show continued U.S. strength.

Evidence on trends in the U.S. trade balance in high-technology products is mixed, with measures of high-technology trade sensitive to which products are included. One measure calculated by Commerce shows the U.S. high-technology trade balance becoming negative for the first time in 1986, but rebounding in subsequent years. Another measure shows that the U.S. share of the world's high-technology exports declined during 1966-86, while Japan's share increased.

High-technology trade measures do have important limitations as competitiveness indicators. First, trade patterns reflect not only performance characteristics of particular goods, but also macroeconomic factors. Second, trade statistics reflect location of production rather than ownership of resources. Research suggests that the export performance of U.S. multinationals has been superior to that of U.S.-produced goods in general in recent decades. Both elements of nationality are relevant to evaluating economic performance and policy alternatives.

Looking beyond the sale of existing high-technology products to other measures of innovative activity, several indicators yield evidence that the technology gap between Japan and the United States has narrowed in recent decades. The United States and Japan had similar levels of R&D spending relative to GNP over the 1980s, with absolute spending higher in the United States. One fact that may be increasingly important is that the U.S. spending advantage is lower when R&D spending for military purposes is excluded from the comparison.

Measures of research output show evidence of Japanese gains. For example, the Japanese share of U.S. patents rose strongly over the past 2 decades, and Japanese researchers increased their scientific publications in the 1980s substantially faster than the world average. However, scientific articles by U.S. researchers continued to far outnumber those of Japanese researchers.

Several surveys of technology experts present what is perhaps the most negative picture of trends in U.S. high-technology performance relative to Japan, concluding that the U.S. leadership position in a number of emerging technologies has been eroded in recent years.

These observed trends are attributable to a variety of factors whose particular impacts are difficult to isolate. The role of the macroeconomic environment is seen most directly in observed trends in high-technology trade aggregates, which are highly correlated with overall U.S. trade performance and with the value of the U.S. dollar. Although macroeconomic policy has important effects on other aspects of high-technology performance through, for example, its role in determining the cost of capital, those effects are less apparent from aggregate indicators. The influence of particular microeconomic factors on aggregate high-technology performance measures is also difficult to isolate. Some direct influences of particular microeconomic government policies on the measures we examined are apparent; for example, trends in the level and composition of R&D spending directly reflect government policy decisions in that the spending includes government-funded R&D. The influence of other microeconomic factors, such as firm and industry structure and government policies directed at particular industries or technologies, likely require more disaggregate performance measures, although even then such analysis would be difficult.

Industry Trends Display Wide Range of Competitive Positions

The 11 particular industries and technologies we examined exhibit a range of trends in competitive position over the past decade, with most of the areas exhibiting some decline in the U.S. position. While these industries and technologies do not constitute a statistically based sample of U.S. high-technology activity, they do illustrate the diversity of that activity and offer some insights into ongoing changes in the technological position of U.S. industry. For several areas examined, the increasing importance of multinational firms complicates assessments of competitive position across countries.

These industries and technologies demonstrate the spectrum of innovative activity, from the basic research that underlies advances in the pharmaceutical industry to the important customer/firm interfaces seen in the sale of robotics. In addition, they include both narrowly defined products, such as supercomputers, and broad industries such as telecommunications equipment, which contains advanced fiber optics systems as well as telephone sets. The particular areas we considered are pharmaceuticals, civilian aircraft, telecommunications equipment, fiber optics, semiconductors, semiconductor equipment and materials, robotics, flexible manufacturing systems, supercomputers, advanced materials, and consumer electronics. Summaries of trends in each of these areas are presented in appendix I, and an overview of these trends is presented in table 3.1.

Table 3.1: Overview of Industry-Specific U.S. Performance Trends

Industry	Trend
Advanced materials	The relative position of the United States and Japan varies across advanced materials categories, with, for example, the United States reported to be lagging in several important areas of electronic and photonic materials and leading in certain structural ceramics with aerospace applications.
Civilian aircraft	Despite strong sales growth and trade performance, particularly in the late 1980s, U.S. firms' share of the world market declined from 73 percent in 1978 to 58 percent in 1989, reflecting in part other countries' successes in developing their own aerospace industries.
Consumer electronics	The U.S. share of world consumer electronics production has declined over several decades so that by the mid-1980s imports into the United States far exceeded domestic production.
Fiber optics	World production data are quite limited for fiber optics. Markets have traditionally been supplied through domestic production; several foreign companies have now set up production facilities in the United States. The United States and Japan are competitive in fiber optics technology, with some reports that Japan has edged ahead.
Flexible manufacturing systems	Flexible manufacturing systems have achieved greater usage in Japan than in the United States, although there is evidence of increased U.S. usage in the late 1980s. During the 1980s, Japanese firms achieved dominance in the production of machine tools that form the basis for flexible manufacturing systems.
Pharmaceuticals	U.S.-owned firms maintained their position as global leaders, having a strong share of the world prescription drug market through 1988 and of the worldwide introduction of new drugs through 1987 (latest estimates available).
Robotics	Substantially more robots are in use in manufacturing in Japan than in the United States. With respect to production, several major U.S. robot firms ceased production in the 1980s. Now the U.S. industry consists primarily of firms that import robotic assemblies and provide accessories. A U.S.- Japan joint venture is one of the world's largest suppliers of robots.
Semiconductors	Although U.S. producers dominated global semiconductor markets through most of the 1970s, Japan became the world's largest supplier by the mid-1980s. U.S. firms continue to show strength in producing several types of semiconductor devices.
Semiconductor equipment and materials	U.S. firms lost world market share in every segment of semiconductor equipment and materials over the 1980s, and the share of Japanese firms rose sharply. U.S. producers have maintained world leadership in several segments of the equipment field.
Supercomputers	U.S. firms supplied almost all of the world supercomputer market through 1984. By 1990, however, their market share was estimated at 68 percent, with the decline due in part to the growth of other markets, particularly Japan where the U.S. share is low.
Telecommunications equipment	The U.S.-based share of both the U.S. and world market declined over the 1980s, as both markets grew. Trends vary substantially within this broad market.

Note: This table is based on material presented in appendix I.

The measures we examined indicate that most of these industries and technologies exhibited some decline in the U.S. leadership position over the 1980s. One exception may be pharmaceuticals, in which U.S. firms maintained their strong position over the decade. The extent to which gaps have been narrowed in technology development and supply of goods varies widely, however. In civilian aircraft, for example, the United States maintained its position as dominant world supplier throughout the decade, although the market share of Europe's Airbus increased. And the United States maintained its world leadership position in supercomputing technology, as Japanese supercomputers, although weak in some areas, saw their competitiveness and market position improve. In contrast, the last of the large volume U.S. robot producers was acquired by a foreign firm in 1990, and U.S.-based firms' share of the semiconductor materials and manufacturing equipment markets fell steadily over the 1980s.

Erosion of U.S. Position Sometimes Greatest in Lower-Tech Industries or Segments

For some industries in which the United States has experienced a substantial decline in relative world position, that decline has been strongest in the less technologically advanced industry segments. Telecommunications, in which the U.S. trade balance and other competitiveness indicators deteriorated markedly in the 1980s, illustrates this phenomenon. Somewhat less clearly, it can be seen in trends in the semiconductor industry. Consumer electronics, from which U.S. firms exited substantially in the 1970s, provides an example in that it contains many products that are not technologically sophisticated. These examples are outlined in the following sections.

Telecommunications: The United States is the world leader in the production and consumption of telecommunications equipment, according to the Department of Commerce. This is a broad industry, including high-capacity transmission systems and long-distance switches at one end and simple telephone sets at the other. It is an industry that has traditionally experienced substantial government regulation, both in the United States and other countries. With the dismantling of the U.S. system of regulation of telecommunications services and equipment, which culminated in the divestiture of the regional Bell telephone companies from the American Telephone and Telegraph Company (AT&T) in 1984, the supply of telecommunications equipment to the U.S. market has been marked by increasing competition. Trade statistics provide one illustration of the increased role of foreign-supplied goods to the U.S. telecommunications equipment market: a 1978 surplus of $1.1 billion in U.S.

telecommunications equipment trade had become a $1.9-billion deficit by 1989.

Telecommunications equipment comprises two broad categories: network equipment, which includes switching equipment and transmission systems; and terminal equipment, which includes telephone sets, answering machines, facsimile (fax) machines, and modems. The greatest erosion in the position of U.S. producers over the past decade has been in the supply of terminal equipment, which is generally characterized by relatively simple technology.

Within this broad grouping of products, competitive and trade characteristics vary widely. In general, the more costly and sophisticated a given product, the more likely that it will be produced or assembled in the United States. Residential telephones, for example, are predominately manufactured abroad, while key telephone systems and private branch exchanges show a significant—although minority—presence of U.S. firms. [1] Fax machines and answering machines, product areas in which foreign firms control most of the patents, have been cited as exceptions to this general rule.

In the category of network equipment, competitiveness measures show a stronger U.S. position. According to the Department of Commerce, there has been little foreign competition, for example, in very large and large long-distance switching machines. U.S. firms also hold a significant lead in high-capacity transmission systems, although Japanese firms are reported to be mounting a challenge in the fiber optic equipment and microwave gear categories. Most international competition in network equipment takes place in the market for smaller, local service switches. Although AT&T held almost half of this market in 1988, foreign-based suppliers' sales—dominated by Canada's Northern Telecom—increased from less than 5 percent of the U.S. market in 1979 to 45 percent by 1987. [2]

Semiconductors: Japan is the world's largest market for and largest producer of semiconductors. Trade association statistics show that Japan's share of world production rose from 32 percent in 1982 to 51 percent in

[1]According to ITA, virtually all of the multinational corporations now active in the U.S. private branch exchange market have some manufacturing facilities in the United States. They note that some of these facilities use primarily imported components and assemblies. Therefore, it is not possible to determine precisely the domestic value added of these operations.

[2]Northern Telecom maintains a major manufacturing and R&D facility for digital switching equipment in North Carolina.

1988 and then declined slightly to 47 percent in 1990. U.S. producers' share fell from 57 percent in 1982 to 37 percent in 1988 and then increased to 40 percent in 1990.[3] Europe's small share of the world market declined over the same period, while production by firms based in South Korea and Taiwan began to reach significant levels.

Semiconductors consist of two main categories of products: discrete devices and integrated circuits. Integrated circuits, the more complex category, are themselves composed of memory devices, logic devices, and the combined product—microprocessors. According to the Department of Commerce, memory devices constitute the fastest growing and most volatile segment of the semiconductor market. Dynamic random access memory devices (DRAM) represent an area in which Japan's growth in semiconductors has been dramatic.

Japanese firms' sales of DRAMs climbed from about 25 percent of the world market in 1978 to about 70 percent in 1988. Although DRAMs have exhibited important technological advances over this period, they are not as technologically sophisticated an item as microprocessors. U.S. producers continue to be quite strong in the market for microprocessors, with 65 percent of the world market. Although the distinction between higher and lower technology products is not as great for semiconductors as for some industries, the variation in market trends among the different products is instructive.

Consumer electronics: Although the definition of consumer electronics is somewhat variable, it is generally considered to include home and automotive audio equipment, television sets, and videocassette recorders. Much of the consumer electronics industry was pioneered by U.S. firms. Over the last 40 years, however, the share of U.S.-owned firms in the domestic and world markets has declined dramatically.

The exit of U.S. producers from the consumer electronics industry has been characterized as consistent with the simple model of profit maximization: Firms found that domestic production of consumer electronics was not sufficiently profitable. With production costs lower in other countries, U.S. producers entered into production agreements with foreign firms and subsequently divested themselves of most of their

[3]These changes in market share for 1990, with the Japanese share decreasing and the U.S. share rising, are due in part to a sharp decline in memory device prices, where foreign firms hold a greater share of the market.

consumer electronics operations. The failure of U.S. firms to successfully capture the potential video recording market, whose technology was developed in the United States, has been ascribed to a combination of business and economic factors.

Much of the consumer electronics market, including television, has long been considered to contain relatively low technology, generating little of the R&D that might have valuable spillovers for other parts of the economy. Some analysts argue that the emergence of high definition television as a viable consumer product may be increasing the technological importance of the industry. Advanced imaging systems, which constitute part of high definition television technology, also have other potentially important applications, including electronic imaging for document storage, and military communications and intelligence.

Multinational Firms and Agreements Complicate Assessment of Trends

The presence of multinational firms—which have grown from just a few to hundreds over the past 3 decades—and the increased number and scope of collaborative international ventures have rendered international assessments of competitiveness difficult on two counts. First, there are conceptual questions to address. For example, does foreign acquisition of U.S. production facilities constitute an erosion of the U.S. position in an industry? Or, if a U.S. firm licenses the manufacturing of a product to a foreign firm, has the competitive position of the United States declined?

Adequate answers to these and related questions require empirical evidence on issues such as the types of investment that foreign firms acquiring U.S. facilities tend to make in this country and the quality of jobs their efforts generate. Thus arises the second source of difficulty in making competitive assessments in areas in which international firms or agreements are important: The data that careful empirical examination of these issues requires are often not available.

Conceptual Issues in Competitive Assessments of Multinational Operations

As U.S. firms have expanded their offshore manufacturing facilities and as foreign direct investment in the United States has increased sharply over the past decade, discussion of the competitiveness of U.S. firms has increasingly begun with the question "who is us?". [4] That is, what is an appropriate measure of U.S. output and performance: the value of goods and services produced on U.S. soil, regardless of the nationality of firms'

[4] This phrase was the title of a 1990 article and gained usage quickly. See Robert B. Reich, "Who Is Us?" Harvard Business Review (Jan.-Feb. 1990).

owners, or the value of goods and services produced by U.S.-owned firms, regardless of where production takes place? In the case of international joint ventures, how should the value of those efforts be ascribed to individual countries?

Several examples illustrate the importance of these questions. A recent study compared the shares of U.S. exports and the exports of U.S.-based multinational corporations, relative to world manufactured exports. The study found important differences between trends in export shares for the two measures: while the U.S. share of world exports declined 30 percent between 1966 and 1988, the U.S. multinationals' share declined less than 10 percent. During the period, the U.S. multinationals supplied an increasing portion of their worldwide exports from foreign production. This trend was even stronger for those industries classified as high technology.

Similarly, a 1990 Department of Commerce study of the electronics industry compared the relative proportions of five major overseas markets served by U.S. computer exports and by U.S. overseas subsidiaries. It found that U.S. overseas investment was the source of more than 60 percent of the value of U.S. computer shipments to these markets in 1986. For example, U.S. firms supplied 58 percent of the West German computer market in 1986, but less than 50 percent of the products included in that figure were manufactured in and exported from the United States. In contrast, in the case of semiconductor materials, the value of production in the United States significantly exceeds that by U.S.-owned firms, due in part to foreign acquisitions of U.S. firms.

Siecor Corporation in fiber optics and GMF in robotics illustrate the importance of joint ventures to these industries. Siecor, a joint venture between Siemens of West Germany and Corning Glass, is one of the two largest producers of fiber optic cable in the United States, accounting for 30 percent of the market. GMF is a joint venture between General Motors and the Japanese firm Fanuc. According to the Department of Commerce, it is the leading supplier of robots to the United States and a major supplier to Europe and Japan. In this venture, manufacturing and most machine-level R&D are performed in Japan.

Thus, assessments of U.S. competitiveness can differ significantly depending on how "United States" is defined. The appropriate definition of U.S. output for the purposes of assessments and policy analysis is the subject of ongoing debate. The answer depends, first, on how firms are believed to operate, including the location of R&D facilities and of high-paying jobs, and the extent and direction of technology flows.

For example, the operations of a Japanese-owned firm with substantial R&D and manufacturing facilities in the United States might be considered to be at least as valuable to the well-being of U.S. citizens as the operations of a U.S.-owned firm that manufactures much of its output abroad. The interests of shareholders versus workers, and the extent to which profits are returned to the country of ownership, are also factors that enter into this assessment. Some argue that the complexity of the "who is us?" issue is in fact increasing, as the relationship between ownership and the location of a firm's most advanced R&D, most sophisticated engineering, and most complex fabrication is becoming harder to predict.

Data Limitations

International performance comparisons are difficult due to limited information on the nationality of ownership of firms. One recent Commerce report, assessing the competitiveness of U.S. efforts in the telecommunications industry, observed that while production and consumption statistics disaggregated by country are available for most products, it is "extremely difficult if not impossible" to collect data by the producer's country of ownership. [5] Officials in Commerce and other government agencies are largely dependent on trade associations and private, often very expensive, data services for such information. These data are of varying reliability, according to those officials. [6]

Several Factors Underlie Performance Trends

Causes of observed performance trends vary among industries, although certain factors may be broadly relevant. Differences in the cost of capital in the United States and Japan in the 1970s and 1980s, for example, are widely believed to have influenced the ability of firms in those countries to undertake investments with longer payoffs. For some of the industries we examined, more microeconomic factors appear important to the impressive performance of foreign competitors. For example, the Japanese government's direction and financial support of R&D efforts, as well as trade protection in the industry's infancy, have been important to Japan's

[5] U.S. Telecommunications in a Global Economy, International Trade Administration, Department of Commerce (Washington, D.C.: 1990), p. 227.

[6] Commerce's Bureau of Economic Analysis collects certain data on the U.S. operations of foreign-owned firms through periodic surveys. For a discussion of evidence from this and other data, see Edward M. Graham and Paul R. Krugman, Foreign Direct Investment in the United States (Washington, D.C.: Institute for International Economics, 1991).

success in semiconductors. Government funding is believed by many to have been central to the emergence of the European Airbus as a strong presence in the civilian aircraft industry. And the continued strength of the U.S. pharmaceutical industry has been attributed in part to a domestic environment that includes high average prices, high levels of government biomedical research, and substantial review of proposed new products. In addition, industrial structure and the management systems favored by many Japanese firms have been identified as important to several Japanese success stories. In the semiconductor equipment and materials industry, for example, the close working relationships between Japanese suppliers and their customers have been credited as key to their impressive performance.

Conclusions

Examination of 11 particular industries and technologies reveals a range of performance trends for U.S. firms, although most exhibited some decline over the 1980s in the U.S. position relative to Japan. For many areas, clear statements of trends are difficult due to variations in performance within the industry or technology. For some industries in which the U.S. position has eroded substantially, that decline has been strongest in the less technologically sophisticated industry segments. The increasing role of multinational firms and international cooperative agreements in these areas further complicates these assessments.

Review of 11 Industries and Technologies

As discussed in chapter 2, there are no ideal standards for measuring high-technology activity or performance. At the industry level, international comparisons based on innovation measures, such as research and development (R&D) expenditures or patent approvals, can be particularly difficult due to data constraints. For marketed products, trends in market share and the balance of trade are useful performance indicators.

Since the individual industry and technology areas we considered vary in terms of how rapidly evolving and how broadly or narrowly defined they are, no single set of measures was appropriate or available for all areas. Our summaries include primarily market share and trade balance data, with conclusions on technology comparisons drawn from industry experts. For robotics and flexible manufacturing systems, evidence on industrial usage for various countries is also presented.

Pharmaceuticals

Background

The U.S. pharmaceutical industry has four primary components: pharmaceutical preparations, diagnostics, medicinals and botanicals, and biologicals. Pharmaceutical preparations is the dominant component, accounting for 82 percent of the value of shipments in 1990. This segment of the industry includes prescription (about 70 percent) and nonprescription (about 30 percent) drugs. Prescription drugs consists of brand name (70 percent) and generic (30 percent) products. The brand name sector is responsible for most industry R&D and for the introduction of new drugs. The role of generics is growing, due in part to expiration of important patents and institutional pressures to contain health care costs. The domestic regulatory environment has been cited as an important factor in the performance of pharmaceutical firms. The environment for U.S. firms includes high average prices and substantial quality regulation.

World Market Share Trends

U.S. firms are regarded as world leaders in the pharmaceutical industry. Some data on share of global prescription sales, by country, are shown in table I.1. U.S. firms maintained a fairly even share of global prescription sales over the 1980-88 period. In addition, in 1985, the United States had 13 of the world's top 25 pharmaceutical firms, ranked in terms of sales, while no other country had more than 4.

Table I.1: Percentage Share of World Pharmaceutical Sales

Country	1980	1984	1986	1988
United States	35	40	37	35
Japan	N/A	N/A	18	20
West Germany	N/A	N/A	13	10
Switzerland	N/A	N/A	8	9
United Kingdom	N/A	N/A	7	9
Others	N/A	N/A	18	17

Note: N/A signifies estimates were not available.

Sources: Henry G. Grabowski, "Innovation and International Competitiveness in Pharmaceuticals," Evolving Technology and Market Structure: Studies in Schumpeterian Economics, eds. Arnold Heertje and Mark Perlman (Ann Arbor: The University of Michigan Press, 1990); and interviews with industry analysts.

Introduction of New Products

Gaining and maintaining world market share in pharmaceuticals are linked to the ability of firms to introduce products that diffuse widely throughout major world markets. The U.S. pharmaceutical industry maintained a strong share of new drug introductions into the world market during 1961-87. Correspondingly, most of the European pharmaceutical industries exhibited declining shares in the 1980s. Japan showed substantial growth in new drug introductions over the period. (See table I.2).

Table I.2: New Drug Introductions, 1961-80 and 1981-87

	1961-80		1981-87	
Country	**Number of new drugs**	**Share**	**Number of new drugs**	**Share**
United States	353	23.6%	77	23.1%
France	271	18.1	26	7.8
West Germany	201	13.4	35	10.5
Japan	155	10.3	93	27.9
Italy	119	7.9	30	9.0
Switzerland	109	7.3	24	7.2
United Kingdom	74	4.9	15	4.5
Others	216	14.4	33	9.9
Total	**1,498**	**99.9**	**333**	**99.9**

Note: Columns of percent shares may not total 100 percent due to rounding.

Source: Henry G. Grabowski, "Innovation and International Competitiveness in Pharmaceuticals."

However, when analysis of new drug introductions is restricted to those products that have received widespread international acceptance (termed "consensus new drugs" and defined as drugs sold in a majority of major markets worldwide), the Japanese position in new drug introductions is less impressive. Table I.3 indicates that the United States had the largest share of consensus new drugs during 1970-85, approximately double its share of worldwide introductions over the period. The Japanese share of consensus new drugs was 4.1 percent.

Table I.3: Consensus New Drug Approvals, 1970-85

Country	No. of consensus drugs	Percent share
United States	85	43.4
Switzerland	27	13.8
United Kingdom	19	9.7
West Germany	17	8.7
Sweden	10	5.1
Italy	9	4.6
Japan	8	4.1
France	5	2.5
Others	16	8.1
Total	**196**	**100.0**

Source: Henry G. Grabowski, "Innovation and International Competitiveness in Pharmaceuticals."

This sharp divergence in Japan's share of total and consensus new drugs appears to indicate that the Japanese have been successful in turning out many new drug therapies, but few have received widespread acceptance. However, analysts report that the Japanese industry has been evolving from an imitative into a more innovative one. In fact, disaggegation of the data in table I.3 has shown that Japan's share of consensus new drugs was rising more recently, with a share of 12 percent for 1979-83.

A recent government study predicts that biopharmaceuticals will be a source of growth in the pharmaceutical industry in the coming decade as companies exploiting discoveries in biotechnology begin to produce pharmaceutical products. The United States is reported to be the global leader in biotechnology research, with European countries having the scientific potential to become strong competitors. Japan is reportedly making strong efforts to improve its scientific capabilities in this area, and the Japanese biotechnology industry is reported to be seeking new products from world firms through joint ventures and licensing.

Civilian Aircraft

Background

Civilian aircraft manufacturing is a major and growing component of the aerospace industry. Civilian aircraft manufacturing includes commercial transports, which dominate the sector, as well as helicopters and general aviation aircraft. U.S. aircraft manufacturers have historically dominated the world market. U.S. civilian aircraft, especially engines, have benefited from large military aerospace R&D expenditures and from economies of scale resulting from the large domestic market. According to industry studies, these traditional advantages have been eroded as the commercial benefits of military aerospace R&D have declined and the aircraft market has become more global.

U.S. Shipments and Trade in Civilian Aircraft

The value of U.S. civilian aircraft sales, measured in real terms, has shown substantial variability over the past 1-1/2 decades. This variability reflects in part the high value of individual sales and also economic factors affecting civilian air travel. In general, the 1980s were first characterized by decreases, then by increases in the real value of U.S. sales. (See table I.4.)

Table I.4: U.S. Civilian Aircraft Shipments and Trade Data, 1975-90

Constant 1990 dollars in millions

Year	Shipments	Exports	Imports	Exports minus Imports
1975	$11,665	$7,346	$183	$7,163
1976	9,918	6,935	194	6,741
1977	8,992	5,549	521	5,028
1978	12,094	7,163	534	6,629
1979	18,352	10,650	878	9,772
1980	20,564	13,002	2,072	10,930
1981	18,917	12,322	2,229	10,093
1982	11,604	6,534	2,155	4,379

(continued)

Constant 1990 dollars in millions

Year	Shipments	Exports	Imports	Exports minus imports
1983	12,659	7,372	1,197	6,175
1984	9,574	5,145	1,614	3,531
1985	12,422	8,007	1,797	6,210
1986	13,819	8,584	2,389	6,195
1987	13,711	8,485	2,300	6,185
1988	17,234	11,191	2,937	8,254
1989	17,843	14,007	2,904	11,103
1990	24,476	18,150	2,794	15,356

Notes: Inflation adjustments are made using the gross domestic product deflator. More precise estimates of real net trade activity would require using specialized trade deflators.

Beginning with 1980, import data include importing of aircraft that have been previously exported from the United States.

Sources: Industrial Outlook, Department of Commerce; and Aerospace Industry Association.

The rise of U.S. civilian aircraft sales in the latter 1980s occurred during a time of decreased growth for sales of military aircraft, and thus the civilian component of total U.S. aerospace sales increased during that period. The civilian component of the industry's order backlog grew from 37 percent in 1985 to 63 percent in 1990; however, civilian sector orders showed some decline in 1991.[1]

The aerospace industry is the leading exporter among U.S. manufacturing industries, and civilian aircraft accounts for a large component of U.S. aerospace exports—46 percent in 1990. Both imports and exports of civilian aircraft have increased over the past 15 years, with the inflation-adjusted trade balance (exports minus imports) fluctuating over the period. These trends are also shown in table I.4.

World Market Share

Despite the sales growth and strong trade performance of the U.S. civilian aerospace industry, its world market share has declined.

The U.S. market share fell from 73 percent in 1978 to 58 percent in 1989. (See table I.5.) This decline reflects the success of other countries in developing their own aerospace industries, often with heavy government support. The table shows that the U.S. market share decline is matched by

[1]The category used in this comparison, civil aerospace, is broader than civilian aircraft in that it includes some civilian spending for space vehicles and launch services.

a rise in the share of the European Community, whose Airbus Industrie—a consortium with involvement by four countries—accounted for 31 percent of the world civilian aircraft market in 1990.

Table I.5: Percentage Share of World Civilian Aerospace Market, 1978-89

Year	European Community	United States	Other
1978	25	73	2
1979	22	76	2
1980	25	74	2
1981	23	74	3
1982	28	68	4
1983	27	69	3
1984	28	69	3
1985	26	71	3
1986	34	62	3
1987	40	56	4
1988	40	56	4
1989	37	58	5

Source: Aerospace Industry Association.

Japan's civilian aircraft industry is quite small relative to those of the United States and Europe, although some believe it will present a long-term challenge. Japan's government has long had an explicit goal of promoting the development of a commercial aircraft industry. Early efforts included heavy government funding. The government has gradually reduced its share of the costs of commercial aircraft projects, as the path to success has proved to be lengthy.

Telecommunications Equipment

Background

Telecommunications equipment comprises two broad categories of products: network equipment, which consists of transmission systems and switches; and customer premises equipment. The latter category includes privately owned equipment, such as telephones, multiline business installations, and private branch exchanges,[2] in addition to fast-growing sectors such as facsimile machines (fax), answering machines, cellular phones, and modems.

U.S. Market Share and Trade Balance in Telecommunications Equipment

As both the U.S. and world markets for telecommunications equipment grew during the 1980s, the U.S.-based share of both markets declined. Competition to U.S. firms from imports intensified over the period, particularly in the market for customer premises equipment. This trend decreased somewhat in 1989 and 1990 when the American Telephone and Telegraph Company (AT&T) and Comdial filed an antidumping complaint against producers in South Korea, Taiwan, and Japan. As for network equipment, U.S. producers still hold a major portion of the market in the United States, particularly in large products such as central office switches. According to International Trade Administration (ITA) officials, they do not collect world market share statistics on an ongoing basis, and obtaining market share data by producer's country of origin for both telecommunications equipment and services is difficult. According to ITA, the decline in U.S.-based firms' share of the world telecommunications equipment market, particularly network equipment, has occurred during a period of slower growth of the U.S. market relative to foreign markets. In addition, non-U.S. markets have been considerably less open to foreign entry, including entry by U.S. firms. According to ITA officials, U.S. firms maintain commercial and technological advantages in high-technology switching and transmissions systems, but these advantages are narrowing.

The U.S. trade balance in telecommunications equipment declined dramatically between 1978 and 1988, from a positive $1,056.1 million to a negative $2,608.4 million. The trade balance went into deficit for the first time in 1983; while its descent abated after 1988, recent trade balance statistics continue to show a deficit. These data show an improvement beginning in 1989; however, interpretations of trends in trade accounts must be qualified due to changes in international trade data reporting categories, beginning in 1989. According to the Department of Commerce, these data-reporting changes account for around one-half of the $700-million improvement in the 1989 telecommunications trade balance.

[2] Private branch exchanges are switches located on customers' premises that are used for handling telephone traffic and data.

U.S. trade deficits in the 1980s originated primarily from customer premises equipment imports from Japan and other Far East nations (e.g., the "Asian newly industrialized countries": Hong Kong, Singapore, South Korea, and Taiwan). In 1990, U.S. trade in network and transmission equipment resulted in a net surplus; however, U.S. trade in customer premises equipment resulted in a net deficit twice as large as the network and transmission equipment surplus.

Product Focus: Facsimile Machines

The facsimile machine became an important part of the customer premises equipment market in the last decade and provides a relevant case study of developments in the telecommunications equipment sector. A fax terminal is a copier equipped to transmit and receive graphic images over telecommunications lines. U.S. manufacturers pioneered facsimile technology, which Japanese firms then developed into a marketable product. Fax machines provided a unique feature in transmitting picture images, which Japanese firms found particularly useful and quickly developed. Now, according to Commerce, foreign ownership of patents limits the ability of U.S. firms to manufacture fax machines and other lower-technology telecommunications products.

During the 1980s, fax machines became one of the fastest growing customer premises equipment sectors in the United States. The Commerce Department reported that sales increased from about $35 million in 1983 to more than $1 billion by 1988. In 1989 growth slowed, and in 1990 actual levels declined. In 1990, Commerce reported that virtually 100 percent of the fax machines bought in the United States were manufactured in Japan. (Those machines sold by U.S. vendors have been manufactured by, or in joint ventures with, Japanese producers.) According to an industry source, fax production in Japan peaked in June 1989 and is no longer expanding. In order to avoid tension in trade relations, Japan appears to be shifting facsimile production to the United States and to Europe, where a build-up in production is expected.

Fiber Optics

Background

Fiber optics systems are based on a technology in which light is used to transport information from one point to another. Telecommunications applications account for the bulk of the market for fiber optics, although there are applications in other areas, including advanced medical, industrial, and military applications. Fiber optics is a relatively new market, with no significant commercial demand before the early 1980s. Components of fiber optics systems include optical fibers, connectors, splicers, cables, transmitters, multiplexers, repeaters, [3] and receivers.

The U.S. and World Market

The U.S. fiber optics market grew rapidly in the early to mid-1980s with new long distance telecommunications installations, and subsequently experienced slower growth. While hundreds of firms in the United States are involved in fiber optics production, several dominate the industry. AT&T and Corning supply about 75 percent of the U.S. optical fiber market, and Siecor and AT&T account for a similar share in fiber optic cable. The U.S. share, in terms of consumption, of the world fiber optics market has been estimated at 38 percent in 1990, down from 54 percent in 1986. The observed decline follows from the later growth of fiber optics telecommunications systems in other countries. (See table I.6.)

Table I.6: Estimates of Fiber Optics' Market Size, Selected Years

Dollars in millions

Year	United States	World	U.S. share of world market (percent)
1986	$829	$1,528	54.2
1987	962	2,073	46.4
1988	1,063	2,535	41.9
1989	1,138	3,190	35.6
1990	1,440	3,779	38.1
1995	3,255	7,225	45.0

Note: Estimates include fiber, cable, and components markets.

Source: The Fiber Optics Industry, ITA, Department of Commerce (Washington, D.C.: 1990).

These estimates of market size were originally made in 1988 but, according to a Commerce official, remain the best available. Data on the industry are poor, according to Commerce, including U.S. trade and shipments data. Census Bureau statistics show domestic shipments of fiber optic systems

[3] A repeater is a device that detects a weak signal in a fiber optic communication system and amplifies and retransmits it.

and equipment, fiber optic cable, and optical fiber. Those categories do not add up to total shipments of fiber optics.

Fiber optics markets have traditionally been supplied through domestic production, both for the United States and for other countries. However, some domestic production is by foreign-owned firms since many foreign companies have set up production facilities in the United States to take advantage of the world's largest fiber optics market. U.S. firms have benefited from important patents in fiber optics. As some of these patents have expired, U.S. industry is reported to be facing increased challenges from foreign producers.

According to a Commerce official, almost all of the optical fiber now produced in the United States is made by U.S.-owned firms. Most fiber optic cable deployed in the United States is also produced by U.S.-owned firms (counting Siecor as U.S. owned), and about half of the fiber optics transmission facilities are supplied by U.S.-owned firms. Joint ventures and licensing agreements have blurred the distinction between domestic and foreign producers. Fitel General (Furukawa and General Cable), Alcoa-Fujikura, and Siecor (Siemens-Corning) are important joint venture operations.

Japan is the second largest producer of fiber optics. Rising Japanese production has outstripped the domestic need for fiber optics, and Japanese firms have been looking overseas for expansion opportunities. Patent and trade issues have served as incentives for Japanese firms to open plants in the United States.

Foreign market access has been of concern to U.S. producers, although, according to a Commerce official, such access has become a less important issue. The official noted that Siecor has had some success in selling fiber optic cable to the national Japanese telecommunications supplier, Nippon Telegraph and Telephone.

Trade

Limited U.S. trade data exist for fiber optics. Import and export statistics are collected for optical fibers and fiber optic cable, although, according to an International Trade Commission official, those segments represent only about 30 percent of the overall fiber optics market. The United States maintains a strong trade surplus in these products. Again, we note that U.S. production by foreign-based firms is significant in some fiber optics categories.

Technology Development

The United States and Japan are considered to be very competitive in optoelectronics, the basic technology behind fiber optics. In the opinion of some experts, Japan has edged ahead. Japanese firms are reported to be developing new technology for higher transmission speeds, transmission methods, and multiplexing techniques. According to a Commerce official, AT&T is also very active in these areas and could make some significant advances; Japan has had an advantage in that it has several major companies developing fiber optics technology, while work in the United States is concentrated in AT&T and a few smaller firms. In 1992, four large U.S. companies formed a consortium to undertake "precompetitive" research in optoelectronic technology.

Semiconductors

Background

Semiconductors are devices that enable computers and other products to process and store information. Growth of the industry was spurred by U.S. defense efforts. In 1965, military demand accounted for about 50 percent of U.S. semiconductor production; by 1975, that figure had declined to about 15 percent. The U.S. semiconductor industry is divided into "captive" and "merchant" producers. Captive producers include large firms that produce for in-house use, while merchant producers sell chips on the open market. Merchant products account for the majority of U.S. semiconductor production. There are several types of semiconductor devices, including memory devices, logic devices, and microprocessors, which handle both memory and logic functions.

U.S. and World Market Trends

Through most of the 1970s, U.S. producers dominated global semiconductor markets. In 1975, for example, U.S. producers supplied over 60 percent of the overall global market and almost 100 percent of the market for dynamic random access memory (DRAM) chips, the most widely used memory chips in computers and other digital equipment. By the mid-1980s, Japan had surpassed the United States as the largest supplier of semiconductors. Since 1986, the relative position of U.S. and Japanese firms in supplying the overall world semiconductor market has not changed substantially. (See table I.7.) Much of Japan's advances came in the DRAM market where, by 1982, the value of Japanese output had surpassed that of the United States. By the end of the decade, U.S. producers were supplying less than 20 percent of the value of DRAM world output.

Table I.7: U.S. and Japanese Shares of World Semiconductor Market, 1982-90

Percentage of dollars

Country	1982	1983	1984	1985	1986	1987	1988	1989	1990
United States	0.57	0.54	0.53	0.49	0.42	0.41	0.37	0.37	0.40
Japan	0.32	0.37	0.37	0.41	0.46	0.48	0.51	0.50	0.47

Source: Semiconductor Industry Association.

U.S. firms have continued to show strength in producing several types of semiconductor devices. U.S. firms lead in production of microprocessors, for example, a growing segment of the semiconductor market, and also are strong in application-specific integrated circuits. Japanese firms do have a significant presence in both areas.

The U.S. trade balance in semiconductors became negative in the early 1980s, with the magnitude of the U.S. trade deficit in this area varying over the decade and showing some decline in 1990. Japan is the largest market for semiconductors and the top import partner for the United States. Thus, access to the Japanese market has been important to U.S. producers.

U.S./Japan Trade Disputes

U.S./Japan competition in semiconductors during the 1980s took place in the legal and political arenas, as well as in the marketplace. In 1985, U.S. producers and the Department of Commerce instituted a series of antidumping actions against Japanese firms, and the semiconductor trade association filed a petition with the U.S. Trade Representative alleging unfair trade practices. In 1986, Japan and the United States entered into a semiconductor trade agreement, which involved specific commitments by Japan regarding market access and dumping. In 1987, sanctions were imposed against Japan for failure to comply with the agreement's market access provisions. Debate continued through 1990 regarding the extent to which those provisions were being honored, although the U.S. government concluded in 1991 that the agreement had resulted in major benefits to the U.S. semiconductor industry.

Semiconductor Equipment and Materials

Background

The semiconductor equipment and materials industry includes those firms that supply the manufacturing equipment and the raw materials used to produce semiconductor devices. The industry includes four main product areas: wafer processing equipment, test and inspection equipment, assembly equipment, and electronic materials. The role of this industry in maintaining U.S. national security was the focus of substantial debate, resulting in the creation of Sematech in 1987. Sematech is a government/industry consortium aimed at improving the technological capabilities of U.S. producers.

U.S. and World Market Trends

The main players in the semiconductor equipment and materials industry are located in Japan, the United States and, to a lesser extent, Europe. In 1980, U.S. firms supplied about 75 percent of the world semiconductor manufacturing and testing equipment market. By 1990 their world market share was surpassed by that of Japanese producers, although 1991 market share figures show some improvement in the position of U.S firms. U.S. firms' share of the domestic semiconductor equipment market remained above 75 percent through most of the 1980s. In the Japanese market, however, which has experienced much higher growth over the period, U.S. firms' share fell sharply over the 1980s. (See tables I.8, I.9, and I.10.)

Table I.8: World Market for Semiconductor Equipment Sales, 1980-91

Dollars in millions

		Market share (percent of dollars)			
Year	Total world sales	United States	Japan	Joint ventures[a]	Others
1980	**$2,228**	75.0%	15.8%	2.2%	7.0%
1981	**2,442**	73.5	17.0	3.0	6.5
1982	**2,739**	69.5	20.8	3.2	6.5
1983	**3,322**	66.1	24.2	3.6	6.1
1984	**6,074**	64.6	25.8	4.0	5.6
1985	**5,964**	64.7	23.5	4.7	7.1
1986	**5,186**	59.0	30.1	3.8	7.1
1987	**5,588**	54.8	32.8	3.2	9.3
1988	**8,184**	49.6	39.3	2.8	8.3
1989	**9,589**	46.8	42.2	2.6	8.4
1990	**10,221**	43.9	47.6	–	8.5
1991	**10,094**	46.7	44.9	–	8.3

[a]Data for 1990 and 1991 do not break out joint ventures' share.

Source: VLSI Research, Inc.

Table I.9: U.S. Market for Semiconductor Equipment Sales, 1980-91

Dollars in millions

		Market share (percent of dollars)			
Year	**Total U.S. sales**	**United States**	**Japan**	**Joint ventures[a]**	**Others**
1980	**$1,337**	89.5%	6.8%	0%	3.7%
1981	**1,401**	88.6	8.1	0	3.3
1982	**1,556**	88.6	8.2	0	3.2
1983	**2,177**	86.5	10.2	0	3.3
1984	**3,179**	84.2	12.3	0	3.5
1985	**3,028**	80.9	14.4	0	4.6
1986	**2,610**	79.5	15.9	0	4.7
1987	**2,577**	74.0	19.5	0	6.4
1988	**3,212**	80.0	14.8	0	5.2
1989	**3,615**	78.7	15.9	0	5.4
1990	**3,917**	76.6	19.4	---	4.1
1991	**3,361**	79.4	14.6	---	6.0

[a]Data for 1990 and 1991 do not break out joint ventures' share.

Source: VLSI Research, Inc.

Table I.10: Japanese Market for Semiconductor Equipment Sales, 1980-91

Dollars in millions

		Market share (percent of dollars)			
Year	**Total U.S. sales**	**United States**	**Japan**	**Joint ventures[a]**	**Others**
1980	**$617**	48.8%	37.7%	7.9%	5.6%
1981	**781**	50.4	35.6	9.4	4.7
1982	**908**	41.1	45.4	9.6	3.9
1983	**1,350**	35.0	50.8	10.3	3.9
1984	**2,116**	35.4	49.9	11.4	3.3
1985	**1,813**	41.3	39.6	15.4	3.8
1986	**1,716**	28.5	57.0	11.4	3.1
1987	**1,979**	31.3	56.0	9.0	3.8
1988	**3,214**	14.1	77.4	7.2	1.3
1989	**3,972**	12.3	79.8	6.3	1.6
1990	**4,360**	14.9	83.9	---	1.2
1991	**4,273**	19.2	79.3	---	1.5

[a]Data for 1990 and 1991 do not break out joint ventures' share.

Source: VLSI Research, Inc.

Japanese firms dominate the world market for semiconductor materials, with 73 percent of sales in 1990 (up from 21 percent in 1980), compared with 13 percent for U.S. firms, and 14 percent for European suppliers. According to an International Trade Commission study, Japanese firms supply over 60 percent of the world's output in 9 of 14 major semiconductor materials categories. A substantial amount of semiconductor materials production takes place outside the country of firm ownership: about 23 percent of actual production was in the United States in 1990, 64 percent in Japan, 7 percent in Europe, and 6 percent elsewhere. The extent of offshore production of semiconductor materials has been attributed to two factors. First, a number of U.S. suppliers have been purchased by Japanese or European firms; second, suppliers have tended to locate production facilities near the markets they serve.

Technological Trends

While U.S. firms lost market share in every segment of equipment and materials over the 1980s, they have maintained world leadership in several segments of equipment. The U.S. industry has fallen substantially behind Japan in photolithography, considered to be the most important technology in semiconductor manufacturing, although there are reports of some bright spots for U.S. firms in photolithography. According to the International Trade Commission, leading semiconductor facilities still require a mix of Japanese and U.S. products, but the dependence of Japanese semiconductor manufacturing on U.S. products appears to be decreasing.

According to the Department of Commerce, U.S. equipment is becoming more competitive, due in part to Sematech. One of Sematech's reputed successes has been in improving relationships between materials producers and suppliers. Assessments of the erosion of the U.S. position in semiconductor equipment and manufacturing have identified close working relationships with customers as an advantage held by Japanese firms compared with their American counterparts.

Robotics

Background

Industrial robots were introduced in the United States in 1961, with significant commercial production by the late 1960s. The American Robotics Industry Association defines a robot as "a reprogrammable, multifunctional manipulator that moves materials, parts, tools, and specialized devices through various programmed motions to perform a variety of tasks." Functions performed by robots include processing, materials handling, assembly, and testing and inspection. International comparisons of robots can be made in two areas: usage and supply. These areas are discussed in the following sections.

International Usage Trends

Comparisons of usage, or diffusion, of robots across countries, particularly the United States and Japan, are complicated by differences in the definition of a robot. Although Organization for Economic Cooperation and Development statistics use a definition similar to that of the United States, Japanese statistics on robot usage often include simpler machines than those fitting the U.S. definition. Table I.11 shows the diffusion of robots across Japan, Sweden, West Germany, France, the United States, Italy, and the United Kingdom.

Table I.11: Number of Robots in Manufacturing for Selected Countries, 1983 and 1988

	Robots per 10,000 employees		Robot population	
Country	1983	1988	1983	1988
Japan	33	117	47,000	176,000
Sweden	16	83	1,452	8,000
West Germany	6	21	4,800	17,700
France	4	18	1,920	8,026
United States	4	17	8,000	32,600
Italy	3	16	1,510	8,300
United Kingdom	3	9	1,753	5,034

Source: National Security Assessment of the U.S. Robotics Industry, Bureau of Export Administration, U.S. Department of Commerce (Washington, D.C.: 1991).

One comparison of robot usage in Japan and the United States, based on a sample of 175 firms across several industries, reported that Japanese firms using robots tended to employ them in larger numbers than firms using robots in the United States. That study found the number of robots used in 1985 (per 10,000 employees) in the Japanese firms surveyed was 4 to 8 times that of U.S. firms surveyed, depending on the industry.[4]

The gap between robot usage in the United States and Japan has been linked to two factors. First, Japanese firms have reported a lower minimum

[4]See Edwin Mansfield, "The Diffusion of Industrial Robots in Japan and the United States," Research Policy, 18 (1989), pp. 183-192. Mansfield restricted his study to include only robots meeting the definition applied by the Robotics Industry Association.

expected rate of return required to justify investing in robots. Second, particularly for small firms, several government-sponsored programs have contributed to robot use in Japan.

International Supply Trends

According to the Department of Commerce, the U.S. robotics industry consists of about 60-70 producers and systems integrators, which import robotic assemblies and subassemblies and provide accessories such as vision systems and motion controllers. A small number produce actual robotic arms, because of particular requirements of their systems. The largest U.S. robot firm is a major global firm founded in 1982 as a joint venture between General Motors and Japan's Fanuc—GMF. GMF provides the market with robots for most applications and is particularly strong in painting. GMF's manufacturing, and most machine-level R&D, is performed in Japan.

During 1979-83, the robotics industry saw substantial new entries into the sector. Declining prices and increasing capabilities caused sales to grow rapidly. U.S. entrants tended to specialize and relied heavily on components from other firms, generally acquiring actual robot arms from foreign firms. Upon GMF's creation, the joint venture firm quickly became a major supplier to the U.S. market.

A period of consolidation began in 1983. Several major U.S. firms ceased production, and others were acquired by foreign firms. The last of the large volume U.S. robot producers was acquired by a foreign firm in 1990. Currently, the U.S. robotics market consists of distributors, accessory equipment suppliers, system integrators, machine vision manufacturers and suppliers, and a handful of actual robot manufacturers. Japan is the world's largest producer of robots. The largest robot-producing firm is ABB Robotics of Sweden. Other producers are in Japan, Germany, Italy, and France, as well as the United States.

The international robot market is characterized by many cooperative agreements. The implications for the United States of joint ventures in robotics have been debated. Joint ventures allow U.S. firms to exploit their position in electronic controls, software, and knowledge of the U.S. market. However, they discourage U.S. producers from developing a capability to produce robot arms, thereby allowing foreign producers to dominate that global market.

Flexible Manufacturing Systems

Background

A flexible manufacturing system is an automated system consisting of processing stations (machine tools or other equipment) linked by a system to move parts from one processing station to another. The machine tools in these systems are primarily numerically controlled machine tools. A flexible manufacturing system can contain many numerically controlled machine tools, although the systems often contain just two or three. The systems can yield economic advantages including increased machine utilization; greater flexibility and product quality; and reduced inventories, lead times, labor costs, and floor space. International comparisons of flexible manufacturing systems can be made in two areas: usage and supply. These areas are discussed in the following sections.

Usage Comparisons

The United States installed the first flexible manufacturing system in 1965. Since 1975, the number of these systems worldwide has grown about 20 to 30 percent per year, a rate of diffusion that has been described as relatively slow. Although flexible manufacturing systems were first introduced in the United States, they have achieved greater usage in Japan over the past 2 decades. Table I.12 presents estimates of the diffusion of systems for several countries. The table indicates a substantial increase during 1985-88 in the number of systems installed in the United States.

Table I.12: Multimachine Flexible Manufacturing Systems, Selected Years

Year	Western Europe	United States	Japan	World
1970	0	5	3	8
1975	2	8	25	48
1980	27	28	71	163
1985	208	90	166	553
1988	410-460	170-190	190-210	1,000

Source: Ellinor Ehrnberg and Staffan Jacobsson, "Technological Discontinuities, Industry Structure, and Firm Strategy—The Case of Machine Tools and Flexible Manufacturing Systems," Unpublished paper, Chalmers University of Technology, Goteborg, Sweden. 1991.

Additional information on relative use of flexible manufacturing systems by country is shown in table I.13, which reflects only large firms, the primary users of flexible manufacturing systems.

Table I.13: Percentage of Firms (with 10,000 or more employees) **With Installed Flexible Manufacturing Systems**

Country or region	Percentage of firms
Japan	67
United States	41
Western Europe	40

Industry	Percentage of firms
Automobiles	53
Electrical equipment	35
Machinery	45
Aerospace	64
Total	**45**

Source: Edwin Mansfield, "The Diffusion of Flexible Manufacturing Systems in Japan, Europe and the United States." Working paper, Center for Economics and Technology, University of Pennsylvania, 1991.

The average estimated rate of return from the investment in flexible manufacturing systems has been reported by one researcher to be lower in the United States than in Japan. This reported finding is consistent with other studies that concluded that U.S. firms have not used these systems as effectively as the Japanese, although it has also been observed that the systems in those earlier studies may not have been entirely comparable. One recent academic study comparing the use of flexible manufacturing systems reported that (1) U.S. firms continue to use the systems to produce fewer parts than firms in Japan or Germany; (2) U.S. firms have lower utilization rates than Japanese firms; and (3) U.S. performance, in terms of using flexible manufacturing systems effectively, is improving.

Supply of Flexible Manufacturing Systems

The flexible manufacturing systems industry overlaps with large sections of the machine tool industry, although the border of the industry has been described as difficult to define. Many of the major installers of flexible manufacturing systems are large machine tool producers.

Computer numerically controlled lathes and machining centers are the two types of numerically controlled machine tools that form the basis for flexible manufacturing systems. Japanese firms are dominant in the production of both of these types of machines. That dominance, and the decline of U.S. production of these tools, is seen in tables I.14 and I.15.

Table I.14: Production of Computer Numerically Controlled Lathes in Japan, Europe, and the United States, Selected Years

	Japan		Europe[a]		United States		Total
Year	Number	Percent	Number	Percent	Number	Percent	Number
1975	1,359	30	1,535	34	1,640	36	4,524
1977	3,900	53	2,332	31	1,178	16	7,410
1979	8,065	58	3,505	25	2,354	17	13,924
1981	12,133	64	4,904	26	2,021	10	19,058
1983	10,020	65	4,106	27	1,203	8	15,329
1984	16,555	72	4,818	21	1,524	7	22,897
1985	19,804	73	5,564	21	1,420	6	26,068
1986	15,988	68	6,438	27	1,163	5	23,589
1987	15,241	69	5,271	24	1,626	7	22,138
1988	20,942	74	5,734	20	1,762	6	28,438

[a]Includes West Germany, France, and Sweden for 1975-84. Includes West Germany and France for 1985. Includes West Germany, France, and Spain for 1986. Includes West Germany, France, Italy, and the United Kingdom for 1987 and 1988.

Source: Ehrnberg and Jacobsson, "Technological Discontinuities."

Table I.15: Production of Machining Centers in Japan, Europe, and the United States, Selected Years

	Japan		Europe		United States		Total
Year	Number	Percent	Number	Percent	Number	Percent	Number
1978	1,377	39	649[a]	18	1,486	42	3,512
1982	6,936	73	1,335[b]	14	1,265	13	9,536
1986	10,882[d]	70	3,784[c,d]	24	918[d]	6	15,584
1987	9,027[d]	67	3,348[d,e]	25	1,036[d]	8	13,411
1988	11,474[d]	69	3,997[d,e]	24	1,277[d]	8	16,748

[a]Includes United Kingdom, West Germany, and Italy. The United Kingdom data are for 1979.

[b]Includes the United Kingdom, West Germany, and Italy.

[c]Includes the United Kingdom, West Germany, Italy, France, and Spain.

[d]Data represent "machining centers and transfer lines, numerically controlled."

[e]Includes the United Kingdom, West Germany, Italy, and France.

Source: Ehrnberg and Jacobsson, "Technological Discontinuities."

The growth of Japanese firms in the supply of numerically controlled machine tools has been linked to their development of smaller and lower-cost computer numerically controlled lathes and machining centers, and to the development of microcomputer-driven computer numerically controlled units.

According to one academic study of the flexible manufacturing systems sold through 1988, 63 percent were delivered by European suppliers, 25 percent by Japanese suppliers, and 12 percent by U.S. suppliers. Because the complex systems require extensive collaboration between buyer and seller, the markets through that period were primarily national: that is, European suppliers supplied most of the European market, Japanese suppliers supplied most of the Japanese market, and U.S. suppliers supplied most of the U.S. market.

Analysts have noted that the flexible manufacturing systems market is becoming more global. They have noted, in particular, the entry of Japanese firms into U.S. and European markets, although efforts by Japanese firms have been described as having varying success. Local distributors play a significant role in the sale of these systems and appear important to Japanese attempts to penetrate markets. The initial focus of Japanese firms in the United States appears to be on selling smaller, standardized systems.

Supercomputers

Background

The first high-performance computers were developed in the early and mid-1970s by two U.S. firms—Control Data Corporation and Cray Research, Inc. U.S. government laboratories, the military, and universities were the initial customers. As the price/performance characteristics of the machines, as well as the software capabilities, improved in the 1980s, a commercial market appeared, including firms in the aerospace, chemical, electronics, and petroleum industries.

Supercomputers have traditionally been defined as very expensive large computer systems with the highest available processing speeds. However, the distinction between supercomputers, mini-supercomputers, and high-speed massively parallel computers is lessening, such that many of the currently available supercomputers are significantly smaller and less expensive than the early models. Traditional high-end supercomputers still account for the majority of industry shipments, but their overall share of shipments has decreased.

Market Trends

According to the Department of Commerce, U.S. firms supplied almost all of the world supercomputer market from 1976 to 1984. Their market share for 1990 was estimated to be 68 percent. U.S. firms still dominate the U.S. supercomputer market, with a market share estimated at 98 percent in 1990. Thus, the U.S. firms' decline in world market share is due largely to the growth of other markets, particularly Japan, in which U.S. share is estimated to be 25 percent. U.S. firms' supply of the European supercomputer market is estimated at about 80 percent. In Europe, U.S. firms have had success in both the public and private sectors. However, according to Commerce, in Japan, where the government has largely restricted procurement to its domestic industry, U.S. firms have sold primarily in the private sector. Two supercomputer agreements between Japan and the United States have aimed at lessening that preference.

Technology Trends

Technological advances in Japanese supercomputers have diminished the lead of U.S. firms. According to an industry analyst, U.S. supercomputing technology held a 4-year lead over that of Japanese firms in 1986, a 2-year lead in 1988, and perhaps a 1-year lead in 1992.

For a number of years, the technological superiority of traditional supercomputers with high-power processors over massively parallel computers with many low-power processors has been debated. According to industry experts, the evidence is in favor of the eventual superiority of massive parallelism. Massively parallel supercomputers have been called a bright spot for the U.S. supercomputer industry.

Advanced Materials

Background

Advanced materials is a broad technology category and a rapidly evolving area of science, with applications ranging from aircraft to computer chips. It is also an area in which international comparisons are difficult and largely subjective, since there is not yet a build-up of statistics that can be compared across countries. Several recent studies have considered status and trends in international position in the development and application of advanced materials. Some conclusions from those studies are outlined in the following sections.

International Comparisons

Reports by the National Critical Technologies Panel (sponsored by the White House's Office of Science and Technology Policy), the privately funded Council on Competitiveness, the Department of Commerce, and the National Research Council have characterized the position of U.S. research and development in advanced materials. The Department of Commerce study reported on advanced materials as a single category and found the United States to be behind Japan and losing ground in this area. The other studies reported a mixed picture, with the United States competitive in certain areas and lagging in others. Two major categories of advanced materials are (1) electronic and photonic materials [5] and (2) advanced structural materials, discussed in the following sections.

Electronic and photonic materials: Although the United States is reported to be competitive with Japan in certain segments of this category, it is considered to be lagging in several important areas. For example, U.S. capabilities have been reported to be behind those of Japan in electronic ceramics, electronic packaging material, and gallium arsenide-based microelectronics. [6] According to one government study, the United States is considered competitive with Japan in fiber optics, although Japan leads in other aspects of photonic materials technology. The United States and Japan are reported to be competitive in superconductor technology.

Advanced structural materials: The studies we reviewed indicate that the relative position of the United States and Japan varies among advanced structural materials categories. For example, according to one government study, the United States leads in development of ceramic matrix composites, particularly with regard to aerospace applications. That study reports Japan to be superior to the United States in the processing of monolithic ceramics for nonaerospace commercial applications. A different assessment shows the United States and Japan to be competitive in certain composites and polymers, with the United States weak in advanced metals and losing ground in structural ceramics.

[5] Photonic materials include those materials that use light and electronics to perform functions now typically performed by electronic devices.

[6] Gallium arsenide is a compound semiconductor material that allows transistors and integrated circuits to operate much more rapidly than similar devices made of silicon.

Materials Focus: Advanced Ceramics

Advanced ceramics is one material that appears in both the electronic and structural applications categories previously mentioned. According to one assessment, the United States leads the world in ceramics research and development and in manufacturing high-performance ceramic matrix composites, partly due to aerospace research efforts. But U.S. users are reported to have been relatively slow to incorporate advanced ceramics into end products. The advanced ceramics industry is concentrated in a few large corporations, including automotive and aerospace firms, as well as manufacturers of traditional ceramics. Electronic ceramics represents a relatively mature commercial application of ceramics and accounts for about 80 percent of the market value of advanced ceramics products, according to the Department of Commerce. This value is incorporated into semiconductors and other electronic components. Structural advanced ceramics, in contrast, is an infant industry. Its most significant application is in automobiles, with applications also in aerospace and other industries.

Technology Focus: Superconductivity

Superconductors are materials that lose all resistance to the flow of electrical current when cooled below a certain temperature. Superconductivity was discovered in 1911, with the first practical superconducting materials found in the 1960s. Superconducting metal alloys are used today in commercial applications in electronics and medicine. Since it has been necessary to cool superconductors to extremely low temperatures, they have required costly and complex refrigeration systems and have not found broad usage.

In 1986, scientists discovered new ceramic high-temperature superconductors. This discovery touched off worldwide efforts to develop superconducting materials with ultimate commercial applications in several areas, including computers, aerospace, and transportation. However, the development of practical superconducting materials poses serious engineering problems, and commercialization efforts have moved forward slowly.

Several studies of superconductivity research efforts and opportunities were issued in 1988 and 1989. They generally concluded that, while U.S. efforts in basic superconductivity research were equal to or better than research efforts in Japan, Japan held an edge in areas of materials processing, manufacturing, and eventual commercialization.

Consumer Electronics

Background

The consumer electronics industry includes products such as home and automotive audio equipment, television sets, and video cassette recorder equipment. Much of the consumer electronics industry has been pioneered by U.S. firms and provides technological links to other industries. The estimated size of the U.S. domestic market for consumer electronics in 1990 was $17.6 billion, consisting of $12.4 billion in imports plus $7.3 billion in domestic product, minus $2.1 billion in exports. [7]

Trends in Market Share and Trade

During the first half of the 20th century, U.S. consumer electronics firms experienced an extended period of innovation and growth. Over the last 40 years, however, the share of U.S.-owned firms in the domestic and world consumer electronics markets has declined dramatically, with U.S. firms withdrawing as foreign competition increased. Beginning with radios in the 1950s, and followed by television in the 1960s and '70s, foreign manufacturers increased their role in supplying these consumer electronic products. More recently, foreign firms have also led in new product innovation and development, such that U.S.-owned domestic market share has been estimated at about 5 percent.

Table I.16 shows trends in U.S. shipments and trade for consumer electronics over the 1980s. Real domestic shipments fluctuated over the period, showing a slight decline, and real exports fell and then rose in the late 1980s. However, the real value of imports of consumer electronics rose sharply during the mid-1980s and then showed moderate fluctuations over the last half of the decade.

[7] "Domestic product" here refers only to the location of the factory, not to ownership.

Table I.16: U.S. Consumer Electronics Shipments and Trade Data, 1980-90

Constant 1990 dollars in millions

Year	Shipments	Exports	Imports
1980	$8,833	$1,644	$6,391
1981	8,062	1,413	7,923
1982	7,298	958	7,152
1983	7,671	772	8,381
1984	8,625	773	11,413
1985	7,556	724	13,550
1986	7,374	772	14,404
1987	6,687	921	12,968
1988	6,630	1,310	12,748
1989	7,439	1,742	13,992
1990	7,319	2,098	12,405

Notes: The data in this table are based on consumer electronics being defined as "Household Audio and Video Equipment " in the Standard Industrial Classification system.

Inflation adjustments are made using the gross domestic product deflator. More precise estimates of real trade activity would require using specialized trade deflators.

Source: Industrial Outlook, International Trade Administration, U.S. Department of Commerce.

During the late 1980s, however, U.S. trade pressure contributed to foreign manufacturers' actions to reduce their country's exports to the United States. Foreign-owned firms, particularly from Asia, shifted production facilities to the United States or Mexico. This shift resulted in a tapering off in consumer electronics imports in the latter part of the decade.

Technology

Much of the consumer electronics market has long been considered to contain relatively low technology. Given historically lower production costs in other countries, the exit of U.S. producers has been characterized as predictable and rational. However, consumer electronics has been a driver of some important technologies, and some analysts argue that the emergence of high definition television as a viable consumer product is increasing the technological importance of the industry. At the same time, existing low-cost manufacturing technology of consumer electronic items has relevance for other industries, particularly data processing and telecommunications.

Major Contributors to This Report

National Security and International Affairs Division, Washington, D.C.

John E. Watson, Assistant Director
James M. McDermott, Assistant Director
Celia J. Thomas, Project Manager
Jaime L. Dominguez, Evaluator

Ordering Information

The first copy of each GAO report and testimony is free. Additional copies are $2 each. Orders should be sent to the following address, accompanied by a check or money order made out to the Superintendent of Documents, when necessary. Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

U.S. General Accounting Office
P.O. Box 6015
Gaithersburg, MD 20877

Orders may also be placed by calling (202) 275-6241.

United States
General Accounting Office
Washington D.C. 20548

Official Business
Penalty for Private Use $300

First Class Mail
Postage & Fees Paid
GAO
Permit No. G100