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Is The United States Losing Its Dominance in High-Technology Industries?

THE RECENT POLITICAL SEASON once again focused attention on high-technology industries and U.S. competitiveness. Many politicians bemoan the loss of dominance in high-technology industries by the United States.[1] The statistics they use to support their argument include the loss of U.S. global market share in high-technology products, the declining U.S. balance-of-payments surplus in high-technology industries and the persistent balance-of-payments deficit with Japan.

Others argue that the U.S. demise has been greatly exaggerated. They point out that labor productivity in the United States remains greater than in other industrialized countries and that the United States spent more than twice as much in absolute terms as other countries on research and development (R&D).

In fact, the evidence is mixed. Although the United States no longer dominates high-technology industries as it did in the 1950s and 1960s, much of that is due to the economic growth of Japan and Germany rather than to a decline in U.S. high-technology industries. As per capita output in these countries converges, one would also expect indicators in high-technology industries to also begin converging. Some indicators, however, suggest that the United States places a relatively smaller emphasis on R&D and education than do Germany and Japan, the main U.S. competitors in the high-tech arena.[2] As a result, few clear conclusions can be drawn.

The goal of this article is to provide a careful, albeit not comprehensive, analysis of U.S. high-technology industries. First, the paper discusses why high-technology industries are considered valuable to an economy and presents evidence to support these arguments. Next, several performance indicators for high-technology industries in the United States are examined. When possible, these indicators are compared with similar indicators in Japan and Germany. The paper concludes with a discussion of what these indicators predict for the future.

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[1] This attitude can be seen, for example, in the hearing *Factors Affecting U.S. Competitiveness* (see U.S. Congress, 1992) and in articles such as "America's High-Tech Decline," in *Foreign Policy* (see Ferguson, 1989).

[2] All statistics for Germany refer to the former Federal Republic of Germany.

WHAT ARE HIGH-TECHNOLOGY INDUSTRIES?

The term *high tech* is often used, but rarely defined. The Organisation for Economic Co-Operation and Development (OECD) defines high-technology industries as having the following characteristics:

- the need for a strong R&D effort;
- strategic importance for governments;
- very rapid product and process obsolescence;
- high-risk and large capital investments; and
- a high degree of international cooperation and competition in R&D production and worldwide marketing.[3]

Unfortunately, although this definition is important in isolating the general industries, these characteristics are too general to be used to classify firms for statistical purposes. The OECD uses the ratio of R&D expenditure to production costs (the R&D intensity) of an industry, which is the defining characteristic of high-technology for which data are available.[4] According to this criterion, the top six R&D-intensive industries in the main 11 countries are aerospace, office machines and computers, electronics and components, drugs, instruments and electrical machinery.[5] These industries had an average R&D intensity of 11.4 percent in 1980, compared with an average of approximately 4.0 percent for all manufacturing industries.

ARE HIGH-TECHNOLOGY INDUSTRIES MORE IMPORTANT THAN OTHER INDUSTRIES?

The special concern expressed about high-technology industries suggests that these industries provide unique benefits absent from other manufacturing industries. These benefits result from the relatively higher amount of innovation in these industries and the subsequent effect on employment, wages, productivity and economic growth.

High-Technology Industries and Economic Innovation

As discussed in the preceding section, high-technology industries are R&D intensive by definition. Innovation, which takes an invention and transforms it into a product or process that a firm can sell or use, generally results from R&D expenditures. Innovations can be broadly divided into three types: process, final product and intermediate product innovations. A process innovation is one that improves the production technique of a product—for example, Henry Ford's use of the moving assembly line to mass-produce automobiles. This innovation dramatically lowered the cost of producing automobiles and significantly increased auto production. An important distinguishing feature of process innovation is that it directly increases the productivity of one or more factors of production (capital, labor, energy and materials).[6] In fact, experts argue the following: process innovation tends to "have a bigger effect on an industry's own rate of productivity increase than does product R&D."[7]

A final product innovation, in contrast, does not increase productivity directly; instead, it introduces a new product or a variation of an existing product that individuals consume. An example of a final product innovation is the refrigerator, which replaced the icebox. Final product innovations generally have a positive effect on the quality of life—for example, refrigerators involve much less maintenance than iceboxes, leaving more free time for other activities—and have a stimulative effect on output.

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[3] OECD (1986). In this paper we consider only high-technology manufacturing industries. Other sectors, such as banking services and insurance, could be considered high tech.

[4] Many variations of this definition are used, in part because some prefer to define high technology in terms of product classes, whereas others (including the OECD) define them in terms of industry classes. Because of data limitations, this paper uses the OECD classification unless stated otherwise.

[5] The main 11 countries, as classified by the OECD, are the United States, Japan, Germany, France, United Kingdom, Italy, Canada, Australia, Netherlands, Sweden and Belgium. The industry classifications differ somewhat from those used by the National Science Board (1991), which classifies the following as high-technology industries: industrial chemicals; drugs and medicines; engines and turbines; office and computing machinery; communication equipment; aerospace; and scientific instruments. This difference is likely due to the fact that the OECD measure is an average over 11 countries in 1980. If a seventh industry were included by the OECD, it would be the automobile industry. The industries classified as high technology according to the OECD classifications have not changed during the course of the sample.

[6] Mansfield proposes using total factor productivity, which is the most general measure of productivity. For a discussion of this measure, see Mansfield (1990).

[7] See Mansfield (1988). Rosenberg (1982) also stresses the importance of improvements to an initial innovation.

Final product innovations, however, do not increase factor productivity directly.[8]

An intermediate product innovation results in a new product that is used to produce another good. In other words, the new product is not consumed by individuals, but rather is used by firms. Productivity increases in industries that use intermediate product innovation. For example, a new machine tool that significantly reduces the time it takes to produce furniture would be considered an intermediate product innovation. Output increases both because the tool industry has a new product and because productivity increases in the furniture industry. Other industries may also benefit if they can adapt the innovation for their own use or if the innovation leads to other innovations. For example, a wood lathe might suggest the possibility of a metal lathe. Innovations that enable a country to produce more output with the same amount of input increase productivity and therefore aggregate output.

Social Benefits from Innovation

Economists have long believed that innovation has a positive effect on economic growth. Schumpeter (1950) argued that the process of creative destruction (the creation of new products that replaced existing products) drives economic growth. Others, such as Solow (1957), estimated the effects of technological change on economic growth. Recently, new growth theorists, such as Romer (1990), Aghion and Howitt (1990) and Grossman and Helpman (1991), have explored the determinants of technological change and its effects on economic growth. They identify endogenous technological spillovers as the primary determinant of economic growth.[9]

Productivity growth is a primary determinant of a country's standard of living. As labor becomes more productive, wages rise.[10] Some economists have argued that technological innovation has a negative effect on employment. The United States, however, has had continued improvements in productivity over the last 100 years, whereas its average unemployment rate has remained essentially unchanged. This suggests that if productivity increases have a negative effect on employment, the effect is not permanent.

Firms invest in R&D because they hope to earn an above-average rate of return on any innovation. The amount of innovation (if any) that results from R&D is always uncertain, so there is no guarantee of a return. As a result, firms expect a greater-than-average rate of return to compensate them for the risk associated with R&D. This return is the cash flow earned over time from an innovation, which includes revenue from product sales, as well as earnings from the leasing or sale of the new technology. The greater the expected return, the greater the incentive to invest in R&D.

The benefits to society from innovation, however, can be substantially larger than the return earned by the innovating firm. The social rate of return measures this benefit. The social rate of return equals the private rate of return plus any technological spillovers, that is, any benefits from an innovation that are not appropriated by the innovator.[11] Because the social rate of return usually exceeds the rate of return the innovator earns, there tends to be a less-than-optimal level of investment in R&D and new technologies.[12] As a result, most countries enact policies that encourage innovation. The most common way is through patent and copyright protection, which improve the likelihood that the innovator will earn an above-normal return on an innovation.[13]

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[8] Because the measurement techniques currently used do not measure changes in quality or nonmarket activities (such as household work), output may or may not increase as a result of the innovation. For a discussion of the problems in growth accounting and measuring the value of innovation, see Griliches (1979) or Grossman and Helpman (1991).

[9] In this context, endogenous technical spillovers refer to the gains in knowledge associated with the process of innovation. For a more comprehensive discussion, see the sources cited in the text.

[10] Situations exist that could make some workers worse off, however. An innovation that substitutes capital for labor may reduce employment in the industry adopting the innovation. Although displaced workers may be worse off in the short run, the lower prices that result from an increase in productivity could increase consumers' purchasing power and increase demand in other industries. As a result, employment could rise in those other industries, leaving aggregate employment unchanged. Of course, there are likely adjustment costs associated with the shift in employment. For a discussion of this issue, see Baumol and McLennan (1985).

[11] For a discussion of alternative measures of spillovers, see Griliches (1979).

[12] The possibility of a significant difference between the social and private rate of return exists because it is impossible to control the flow of information generated by an innovation. See Arrow (1962) for a careful discussion of this problem.

[13] See Butler (1990) for a discussion of the relationship between property rights and innovation.

Governments often provide other incentives, both explicit and implicit, to innovate. Tax credits, for example, are offered for R&D in many industrial countries.[14] Many governments also provide funds for R&D, both directly and indirectly, by subsidizing education. In fact, the United States, though it has no explicit industrial policy, publicly finances nearly half of all R&D in the country (an estimated 43.5 percent in 1991).

International Effects of Innovation

The benefits of an innovation, particularly its indirect benefits, are not restricted geographically. To the extent that knowledge generated from innovation is internationally available, countries benefit from all innovation, regardless of where it originates. In general, the gains from innovation are greater in the innovating country than in countries that import the technology because of the increased jobs and higher wages associated with high-technology industries. In addition, the innovating country benefits from earnings on the sale or lease of new technology to other countries. The extent to which a nation benefits from domestic innovation depends greatly on the degree to which that nation is compensated for the innovation-related knowledge and technologies that flow abroad.

Technological innovation, particularly process innovation, has historically traveled slowly because of international capital and labor immobility, as well as linguistic and cultural differences. Mansfield (1984) discusses another reason why process innovation disseminates slowly across borders: Firms are often unwilling to license new technology abroad because it is difficult to control the diffusion of the technology in other countries. This licensing argument should not apply within firms, however. The recent growth of multinational corporations, such as IBM and Toyota, in high-technology industries has significantly increased the pace of technological diffusion internationally.

Regardless of whether impediments to the flow of information or technology exist, however, an innovating country still benefits from innovation through both the private and social returns generated. If process improvements to an initial innovation are made in the innovating country, the benefits of the initial innovation are even greater over time for that country because of increases in productivity.

Evidence Regarding High-Technology Industries

A 1960 National Bureau of Economic Research conference was specifically designed to examine inventive activity, the activity that generates innovation. One of the conference papers discussed the chemical, allied products and pharmaceutical industries between 1947 and 1957 and found that "productivity increases are associated with investment in the improvement of technology and the greater the expenditures for research and development the greater the rate of growth of productivity."[15] More recent studies also found R&D to be an important determinant of innovation and productivity and therefore economic growth.[16] In addition, researchers have found significant differences between the social and private rates of return earned on innovations, supporting the view that the benefits to society from innovation are greater than those appropriated by firms.[17] Unfortunately, these results must be viewed with some skepticism because of measurement and data problems.[18]

Another way high-tech industries benefit a country directly is through their effect on wages and employment. In general, wages might be expected to be higher in innovating industries because producing and developing new products or implementing new processes initially requires a higher skill level. Existing wage and employment data in U.S. high-technology industries support this theory. In 1972, wages in high-technology industries were 16.7 percent higher than wages in all other manufacturing industries. By 1989, wages in high-technology industries were 24.7 percent higher.[19]

U.S. compounded annual employment growth

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[14] Some empirical evidence of the effect of tax credits for R&D suggests that their importance in the United States may be modest. See Mansfield (1986) and Cordes (1989). A recent study by Hall (1992) finds stronger support for the effectiveness of R&D tax credits.

[15] See Minasian (1962, p. 94). Recall that increasing the rate of productivity increases economic growth. Output may not necessarily increase if the result of an innovation is a substantial increase in leisure relative to hours worked.

[16] See, for example, Leonard (1971), Mansfield (1980) and Scherer (1982).

[17] See, for example, Mansfield (1981) and Bernstein and Nadiri (1988, 1989).

[18] See Griliches (1979) and Grossman and Helpman (1991) for a discussion of these problems.

[19] This rise in wages could be due to an increase in the demand for skilled labor that exceeds the supply. See Katz and Murphy (1991).

rates between 1970 and 1989 were among the highest in the pharmaceuticals (3.3 percent) and aircraft (3.2 percent) sectors. Employment declined in most lower-technology U.S. industries; the largest declines were in ferrous metals (-2.4 percent) and other transport equipment (-2.5 percent).[20] On average, the compounded annual employment growth rate for all manufacturing industries was 0.2 percent during this period.

Wage differences in high- and low-technology industries can be seen in many industrialized countries. In 1988, wages in high-technology industries for the Group of Seven countries were on average 26.5 percent higher than wages in low-technology industries.[21]

TRENDS IN HIGH-TECHNOLOGY INDUSTRIES

Both the theoretical and empirical evidence of the benefits associated with innovation suggest that R&D-intensive industries are particularly valuable to a country. U.S. high-technology industries dominated the world market for most of the postwar period. In the last two decades, however, this dominance appears to have deteriorated, as reflected by the declining U.S. share of high-technology manufacturing output in the OECD since 1970. This section looks at several indicators of current and future performance in high-technology industries for the United States.[22] The next section compares some of these indicators with those of Japan and Germany.

High-Technology Indicators for the United States

Table 1 shows various statistics on U.S. R&D. High-technology manufacturing output increased by more than 50 percent in 10 years—from 20.0 percent of total manufacturing output in 1980 to 30.4 percent by 1990.[23] This marked increase occurred at the expense of other manufacturing industries. Manufacturing output as a percent of gross domestic product (GDP) remained fairly constant over this period.

Statistics on gross expenditures on R&D (GERD) and business expenditures on R&D (BERD), which are available over a longer period, provide mixed evidence on the behavior of U.S. R&D. Figure 1 shows the components of GERD for 1991, with BERD clearly being the largest component. BERD is divided to show the percent of business R&D that is government funded. Both GERD and BERD have risen in real (constant-dollar) terms since 1975. As a percent of GDP, however, both GERD and BERD have fluctuated since 1970, falling until 1978, rising from 1978 to 1985 and declining since then.[24] Many of the fluctuations have been in defense-related expenditures on R&D. Nondefense spending on R&D as a percent of gross national product (GNP) increased slightly, from 1.6 percent in 1972 to 1.9 percent in 1989.

An important caveat to these numbers results from the problems associated with using an aggregate deflator (such as the GDP deflator) for R&D expenditure. One study found that because of the inadequacies in the deflator used, real R&D expenditures in the period 1969–79 rose only 1 percent—not the 7 percent reported using a standard deflator.[25] In fact, most evidence suggests that R&D costs increase more rapidly than the R&D deflator.[26]

Another indicator of R&D activity can be obtained by examining its components—basic research, applied research and development. According to the National Science Foundation, basic research is "research that advances scientific knowledge but does not have specific commercial objectives."[27]

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[20] The compounded annual growth rate for the aircraft and other transport equipment industry was calculated for the period 1972–89. The other transport equipment category is transport equipment less shipbuilding, automotive and aircraft.

[21] The Group of Seven countries are Canada, France, Germany, Italy, Japan, United Kingdom and United States. Because of data limitations, this wage comparison uses a broader definition of high technology.

[22] Some analysts use patent statistics as an indicator of inventive activity. According to Cockburn and Griliches (1988), however, "Data on R&D expenditures...are stronger measures of input to the process by which firms produce technical innovation than patents are of its 'output.' " In addition, cross-country comparisons of patent statistics are often invalid because of varying standards across countries. Thus patent statistics can be used to compare changes within a country over time, but not across countries.

[23] Table 1 uses the National Science Board definition of high technology.

[24] To get a sense of the magnitudes being examined, a 0.1 percent change in GDP in 1990 equals $5.5 billion.

[25] See Mansfield (1984).

[26] See Bureau of Labor Statistics (1989). Unfortunately, no standard series on an R&D deflator for the United States is available. Available estimates are not consistent with the series shown above. These series were used because they are internationally comparable.

[27] See National Science Board (1991).

Table 1
High-Technology Indicators for the United States

Year	GERD (billions of 1982 dollars)	GERD as a percent of GDP	BERD (billions of 1982 dollars)	BERD as a percent of GDP	Hi-tech manufactures as a percent of total manufacturing output	Manufacturing as a percent of GDP in 1982 dollars[1]
1970	65.27	2.72	43.02	1.79	N.A.	21.12
1975	61.93	2.32	40.79	1.53	N.A.	20.54
1980	74.90	2.39	51.93	1.66	20.0	21.52
1981	78.38	2.45	55.12	1.72	20.7	21.25
1982	81.69	2.62	58.65	1.88	22.4	20.37
1983	87.51	2.71	62.82	1.95	22.9	20.87
1984	95.86	2.78	69.45	2.01	24.5	21.76
1985	104.62	2.93	75.96	2.13	25.5	21.75
1986	106.85	2.91	76.78	2.09	27.0	21.78
1987	108.62	2.87	78.43	2.07	27.9	22.24
1988	112.28	2.83	80.63	2.04	28.7	23.25
1989	114.66	2.82	80.44	1.98	29.6	22.73
1990	114.65	2.80	79.24	1.93	30.4	N.A.
1991	N.A.	2.82	N.A.	1.95	N.A.	N.A.

DEFINITIONS:
GERD—Gross expenditure on research and development
BERD—Business expenditure on research and development
GDP—Gross domestic product
[1] Two different deflators were used for this calculation.

SOURCE: OECD, Science and Technology Statistics (1992); National Science Board; Economic Report of the President.

Applied research is the application of new scientific knowledge to determine how a specific problem or need can be met. For industry this includes specific commercial objectives. Development, on the other hand, is the "systematic use of the knowledge or understanding gained from research directed toward the production of useful materials [and] devices...including design and development of prototypes and processes."[28] Thus research is necessary for invention, but development is required to bring an invention to market. That is, development is required for innovation. Between 1960 and 1990, the allocation of R&D expenditures within these categories remained essentially unchanged.

Some commentators have expressed concern about the lack of relative increase in development expenditures. They believe that such expenditures are critical for future technological progress. This argument is particularly relevant concerning new and improved production processes, which have a more direct effect on productivity. For example, the President's Commission on Industrial Competitiveness states the following: "It does [the United States] little good to design state-of-the-art products, if within a short time our foreign competitors can manufacture them more cheaply."[29] According to Mansfield (1988), despite these criticisms there is nothing to "indicate that there was any perceptible increase between 1976 and 1985 in the proportion of [U.S. firms'] R&D expenditures devoted to new or improved processes."

Overall, these statistics appear to contradict the idea that R&D expenditures by U.S. high-technology industries declined in the 1980s. Since 1985, however, R&D as a percent of GDP has been declining. This relative decline may be

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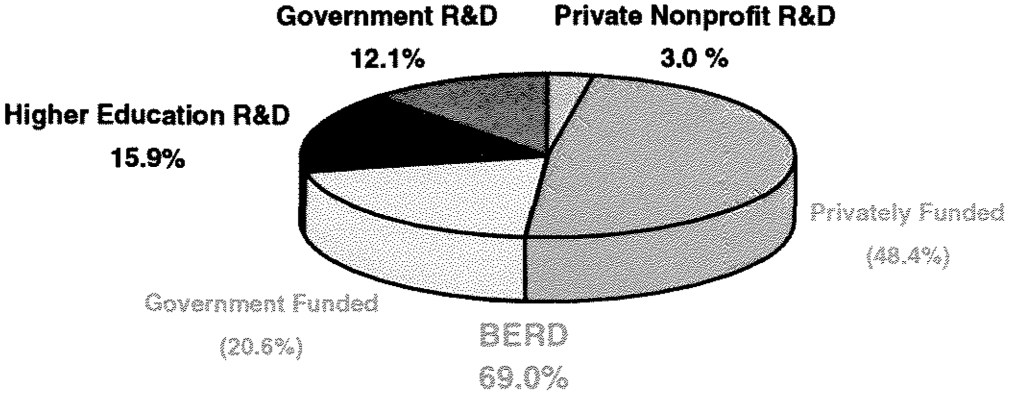
[28] See National Science Board (1991).

[29] Cited in Mansfield (1988).

Figure 1
Components of GERD, 1991



a cause for concern, for both productivity growth and performance in high-technology industries.[30]

AN INTERNATIONAL COMPARISON IN HIGH TECHNOLOGY

Much of the concern about U.S. high-technology performance has focused on U.S. indicators relative to those of other countries. This section compares U.S. high-technology performance with that of Japan and Germany.[31] Because of the sheer size of the United States, its total R&D expenditures are much greater than those of Germany or Japan. For example, using OECD purchasing-power parities to convert to dollars, GERD in 1990 was $66 billion in Japan, $28 billion in Germany and $151 billion in the United States.[32] As a result, the United States can benefit from the additional resources it can spend on R&D, to the extent that its R&D is at least as productive as R&D in the other two countries. Several researchers have expressed concern regarding the productivity of U.S. R&D, particularly in regard to other countries.[33] One reason for this is the high percentage of R&D funded by the government. Studies have found that government-funded private R&D is less productive than privately funded business R&D.[34]

Figures 2 and 3 show GERD and BERD as a percent of GDP for the three countries. Throughout most of the last 20 years, the United States has had higher GERD/GDP and BERD/GDP ratios than Germany and Japan.[35] From 1964 to 1990, Japan and Germany each increased its GERD as a percent of GDP by approximately 100 percent. From 1980 to 1990 (1981 for Germany), however,

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[30] The effects of R&D are estimated to have about a two-year lag on productivity. A longer lag is associated with basic research (Bureau of Labor Statistics, 1989).

[31] In 1989, the average expenditure on GERD as a percent of GDP for these three countries was 2.9 percent, compared with the OECD average for reporting countries, which was 1.7 percent. This statistic excludes Australia, Belgium and Portugal. If they were included, the number would likely be slightly lower.

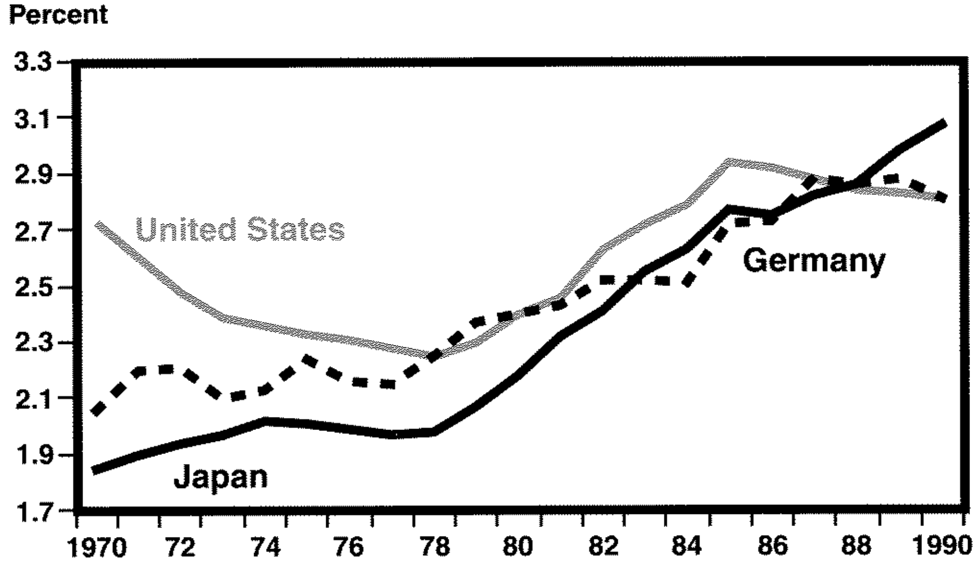
[32] Purchasing-power parities measure the number of U.S. dollars required in each country to buy the same representative basket of final goods and services that cost $100 in the United States.

[33] See Scherer (1982) and Mansfield (1988). Mohnen, Nadiri and Prucha (1986) compared the rate of return on R&D in the three countries and also found that the return was lowest in the United States.

[34] See Griliches (1986, 1987).

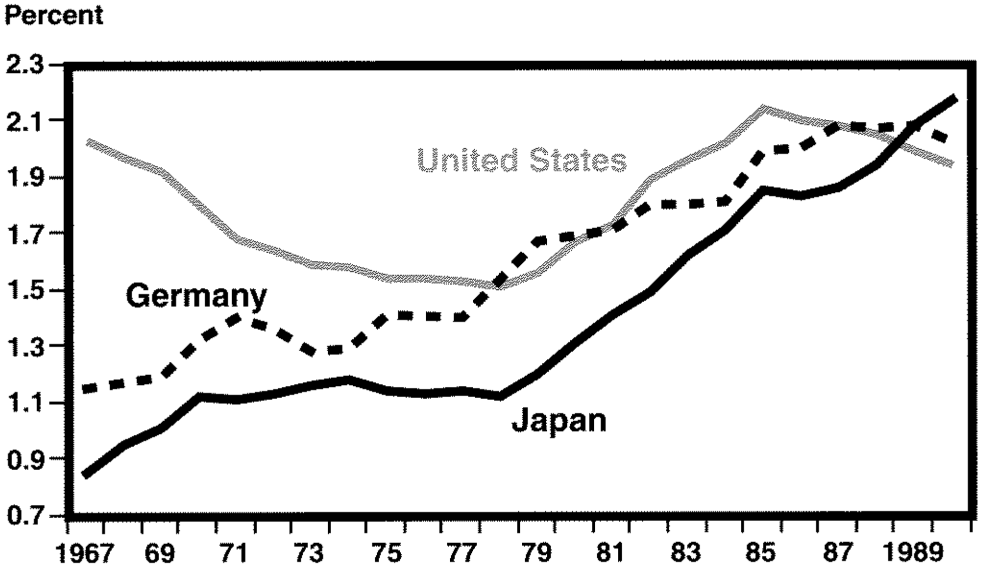
[35] Because of the problems associated with using standard deflators for R&D, these numbers could be somewhat misleading. If, for example, R&D costs rose faster in Japan relative to GDP than in the other two countries, the actual ratio for Japan would be relatively lower. The only attempt to calculate R&D deflators across countries was done by the OECD (1979) for the period 1967–75. The results suggested that the R&D deflator moved together for these countries. Unfortunately, the deflators for Japan and Germany were not directly comparable, and a deflator was not calculated for the United States. As a result, it is difficult to predict whether the price of R&D would move differently across countries. A worldwide program has attempted to produce international comparisons of variables in the National Income and Product Accounts across countries. See Kravis and Lipsey (1990) for a summary and update on this program.

Figure 2
GERD as a Percent of GDP



U.S. data for 1971 and German data for 1980 were not available.

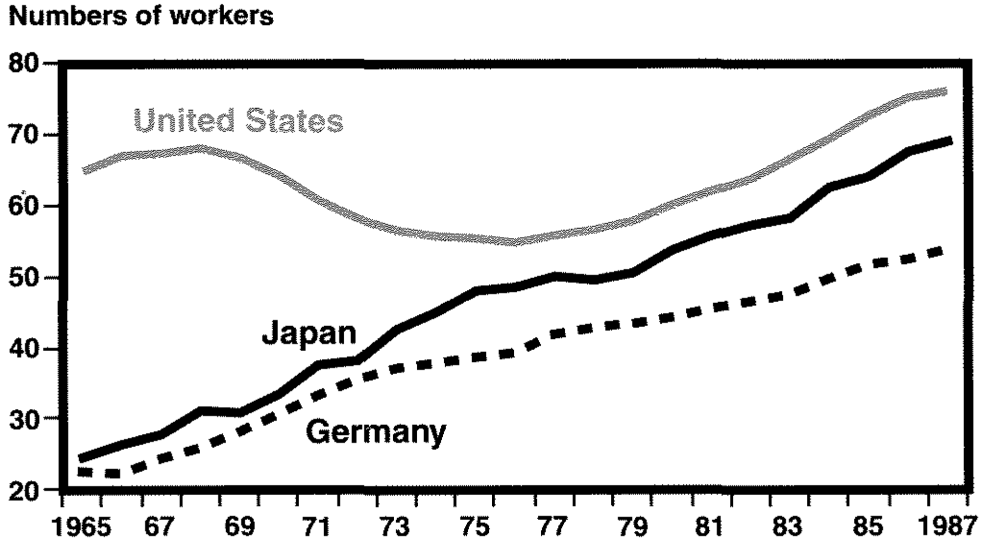
Figure 3
BERD as a Percent of GDP



German data for 1976, 1978, and 1980 were not available.

Figure 4

Scientists and Engineers Working in R&D per 10,000 Labor Force



The figure for Germany increased in 1979 because the 1979 survey includes small and medium enterprises not surveyed in 1977.

Data for Germany in 1978, 1980, 1982, 1984, 1986, and 1987 are estimated.

SOURCE: National Science Board, 1991.

Japan's increase in GERD as a percent of GDP was 40.8 percent, much higher than the 15.6 percent increase in Germany or the 17.2 percent increase in the United States. BERD as a percent of GDP also increased steadily in Japan and Germany over the last 23 years, whereas U.S. spending fluctuated during the same period. By 1990 the ratios were essentially equal in the three countries.

The lack of variability in other countries could be attributed to the low level of military spending in these other countries. For example, in 1989, 28.9 percent of U.S. R&D was defense related, compared with 4.6 percent of Germany's R&D and less than 1.0 percent of Japan's R&D.

Another measure of innovative activity is the number of science and engineering (S&E) personnel relative to the total workforce (see figure 4). Throughout the sample, the United States has employed more S&E personnel per 10,000 workers than either Germany or Japan. Although the number of S&E workers relative to the labor force has risen on average in all three countries, the increase has been substantially greater in Japan and Germany. As a result, this difference among the three countries has narrowed considerably.

The technological balance of payments (shown in table 2) measures the difference between receipts and payments related to earnings on technology and is an indicator of the degree to which a country is an exporter or importer of technology. This measure includes revenues associated with the use of patents, licenses, trademarks, designs, inventions, know-how and closely related technical services. This balance has been steadily increasing for the United States since 1969 (the first year data are available), showing that earnings on U.S. technological exports continue to significantly exceed U.S.

Table 2
International Comparisons in High-Technology Indicators

	High-tech manufactures' share of total manufacturing output[1] (percent)			Technology balance of payments[2] (billions of U.S. dollars)		
Year	U.S.	Japan	Germany	U.S.	Japan	Germany
1971	N.A.	N.A.	N.A.	2.30	−0.44	−0.32
1975	N.A.	N.A.	N.A.	3.83	−0.37	−0.45
1980	20.0	16.3	16.1	6.36	−0.32	−0.56
1985	25.5	24.6	20.4	5.10	−0.27	−0.65
1986	27.0	26.4	20.8	6.19	−0.17	−0.55
1987	27.9	29.5	20.9	7.70	−0.32	−0.60
1988	28.7	32.9	21.3	8.80	−0.32	−0.65
1989	29.6	34.5	20.6	9.57	0.00	−1.05
1990	30.4	35.1	20.3	12.65	−0.17	−0.93

[1] National Science Board definition.

[2] OECD purchasing-power parties are used to convert yen and deutsche marks to dollars.

SOURCE: National Science Board, Science and Engineering Indicators (1991); OECD, Science and Technology Statistics.

payments for technological information. Japan and Germany have both, on average, increased their exports of technology during this period. By 1989 Japan exported as much technology as it imported, suggesting that, contrary to popular perception, Japan is becoming an innovator in its own right.

The increased importance of high-technology industries in these countries can also be seen by looking at international comparisons in high-technology indicators (see table 2).[36] High-technology manufactures as a percent of total domestic manufacturing output rose by more than 100 percent in Japan between 1980 and 1990. This ratio increased in the United States and Germany, although by significantly less—52.0 percent and 26.1 percent, respectively.

In the last 10 years, the market for high-technology products in OECD countries has increased by 117 percent in constant (1980) dollars. Output in high-technology industries rose in Japan, Germany and the United States during this period. However, despite the 92.9 percent increase in the value of its high-technology output from 1980 to 1990, the U.S. share of global high-technology manufacturing declined by 11.1 percent. Germany's share declined 20.3 percent during this period as well, and the share of the remaining OECD countries as a whole declined 13.6 percent (see table 3). As these countries lost market share, Japan's market share increased 58.7 percent. Thus although the United States remains the major producer of high-technology goods, it no longer dominates all high-technology industries.

The composition of high-technology goods production also changed markedly during these 10 years. For example, the U.S. share of global production of office and computing machinery fell by 15.2 percentage points, whereas Japan's share rose an offsetting 15.5 percentage points. Similarly, the U.S. share of radio, television and communications equipment declined 6.0 percentage points from 1980 to 1990, whereas Japan's share of this global market increased by 15.6 percentage points. This suggests that the United States has faced increased competition in these industries. On the other hand, its position in industrial chemicals, drugs and medicines remains essentially unchanged, and its market share of scientific instruments increased somewhat.

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[36] The rest of this section uses the National Science Board definition of high-technology industries. Because the board changed from the OECD definition in its 1991 report, a longer consistent time series for these variables is not available.

Table 3

Country Share of Global Market for High-Tech Manufactures, by Industry: 1980–90 (in percent)

	1980	1981	1982	1983	1984	1985	1986	1987	1988 (est.)	1989 (est.)	1990 (est.)
High-tech manufactures											
United States	40.4	39.5	38.9	37.8	37.9	36.3	36.9	37.5	37.0	36.0	35.9
Japan	18.4	19.7	20.4	21.6	23.3	23.6	23.4	25.1	26.5	28.4	29.2
Germany	11.8	11.7	11.8	11.8	11.3	12.0	11.5	10.5	10.1	9.5	9.4
Industrial chemicals											
United States	32.7	33.1	29.8	29.2	28.0	25.8	28.5	31.4	31.2	32.2	32.5
Japan	16.1	14.4	15.3	14.0	14.1	13.4	12.1	13.1	12.7	13.4	14.1
Germany	16.2	16.9	17.9	19.1	19.5	20.4	20.4	18.5	18.7	18.8	18.4
Drugs and medicines											
United States	29.6	29.6	30.3	30.3	30.4	30.0	30.4	31.4	31.4	30.8	29.2
Japan	21.2	21.7	22.1	22.0	21.2	20.7	20.4	19.9	20.1	20.1	20.3
Germany	13.1	13.1	12.5	12.5	12.7	12.3	12.1	11.4	11.5	11.4	10.9
Engines and turbines											
United States	44.2	37.9	35.0	33.0	35.4	34.8	35.4	35.4	35.8	35.2	34.9
Japan	18.4	16.1	17.9	18.8	18.0	17.0	14.9	15.7	15.5	15.8	15.3
Germany	11.3	9.9	9.0	9.4	10.3	11.2	10.9	11.2	10.7	10.8	11.6
Office and computing machinery											
United States	50.0	49.0	49.1	45.2	44.0	39.6	37.8	38.1	37.3	35.6	34.8
Japan	22.0	23.0	24.0	27.2	27.5	30.2	30.8	31.8	33.3	34.6	37.5
Germany	6.5	7.4	7.0	7.0	7.4	8.3	8.0	7.1	6.6	5.5	5.4
Radio, TV and communication equipment											
United States	36.6	34.8	35.0	34.0	33.8	32.9	32.8	32.3	31.5	29.9	30.6
Japan	26.4	30.5	30.7	32.2	35.5	34.0	33.0	36.5	39.3	42.9	42.0
Germany	12.0	11.4	11.4	11.1	9.8	11.3	11.6	10.3	9.6	9.5	10.0
Aircraft											
United States	57.6	56.4	56.6	55.8	58.7	57.9	59.5	58.7	59.2	56.4	55.9
Japan	2.2	2.4	2.3	2.4	2.5	2.9	2.5	2.8	3.2	3.6	3.6
Germany	4.8	5.3	6.0	5.4	5.0	5.0	4.4	4.6	4.7	4.6	4.8
Scientific instruments											
United States	49.1	49.0	50.5	50.0	50.4	48.4	48.4	50.8	51.5	52.7	53.4
Japan	17.6	19.2	18.1	19.0	19.0	19.7	18.9	18.1	16.2	16.1	15.4
Germany	11.4	10.8	10.2	9.8	9.8	10.8	11.1	11.1	11.4	10.8	11.1

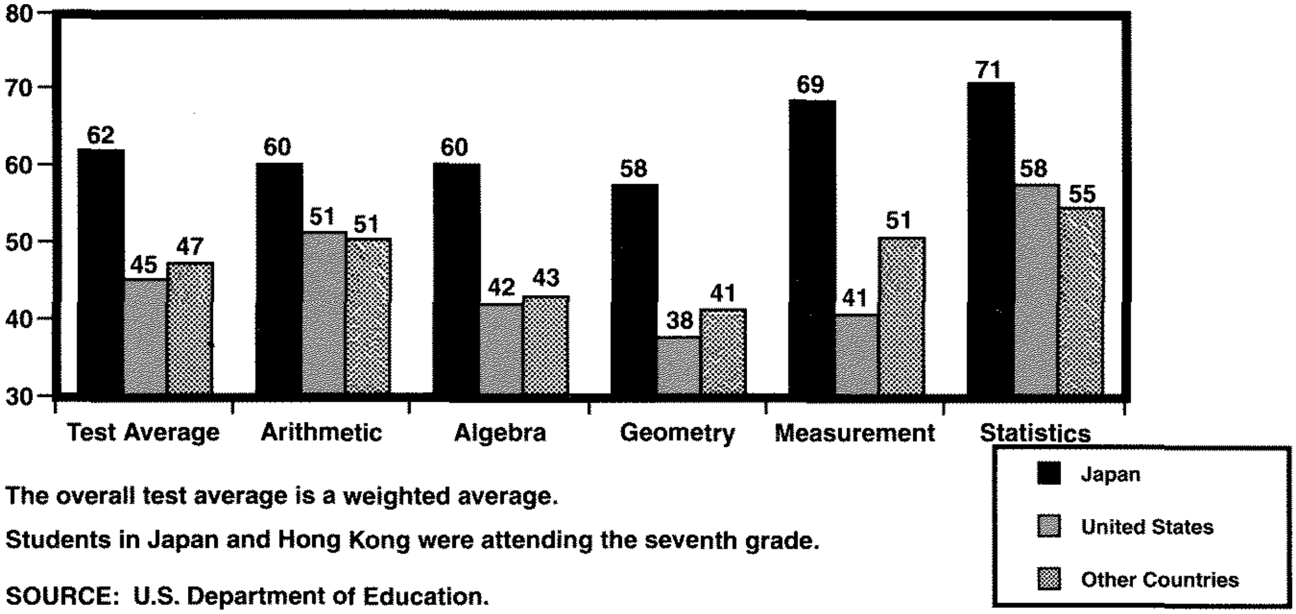
NOTES: Total shipments by OECD countries are used as a proxy for global output. Shares represent each country's shipments as a percentage of OECD shipments. Germany refers to the former Federal Republic of Germany.

SOURCE: See National Science Board (1991).

Figure 5

International Comparisons in Education

Average mathematics test scores for eighth-grade students, 1981-1982



The overall test average is a weighted average.

Students in Japan and Hong Kong were attending the seventh grade.

SOURCE: U.S. Department of Education.

Whether the United States will continue to be a world leader in high-technology manufacturing is unclear. Although its relative position in high-tech manufacturing has slipped in the past decade, so have those of many other industrialized countries, with Japan gaining most of the lost market share.[37] On average, the U.S. decline was less than those of European countries. Furthermore, it seems unlikely that any country could maintain the degree of dominance that the United States enjoyed in the early postwar period. Even if the United States had continued to increase its high-tech manufacturing at the same rate as in the postwar period, the entry of other countries into high-technology industries would have guaranteed a loss of market share for the United States. Hence the recent loss of world market share itself is not cause for alarm, given the significant output increase in U.S. high-tech industries during the period.

WHAT IS LIKELY FOR THE FUTURE?

Concern remains that hidden in these trends is the future decline of U.S. high-technology industries. Given the higher skills necessary for both employment in high-technology industries and success in R&D, the education level and scholastic performance of U.S. students (relative to those in other countries) is coming under increased scrutiny. A possible indicator of future performance in high-technology industries, educational performance comparisons, is presented in figures 5 and 6. International education comparisons are extremely difficult because of the differences in educational systems. As a result, these statistics should be viewed only as suggestive.[38]

An international assessment study comparing students from 18 countries found significant

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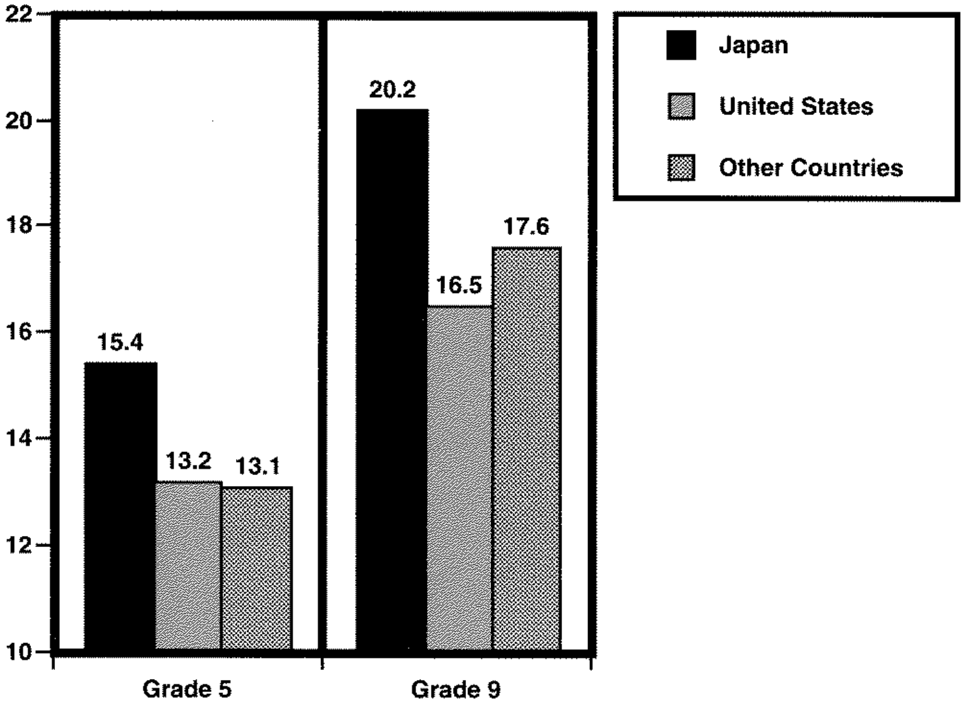
[37] The United Kingdom substantially increased its share of several high-technology industries and its share overall. Data were not presented for the United Kingdom, however, because the R&D series is incomplete and its R&D expenditure as a percent of GNP is significantly lower than for the countries presented (2.0 in 1989).

[38] For the complete comparisons, see original source.

Figure 6

International Comparison in Education

Science test scores for fifth- and ninth grade students—1983-1986



Tests were administered between 1983 and 1986. The average age in years and months is 10:9 for fifth-grade students and 14:10 for ninth-grade students.

SOURCE: International Association for the Evaluation of Educational Achievement.

differences in the performances of U.S. and Japanese students (Germany did not participate).[39] In fact, the U.S. ranking in geometry was eleventh, and its ranking in measurement was twelfth out of the 12 industrialized countries that participated in the tests. In a different study of science test scores for 10- and 14-year-olds, the U.S. students ranked significantly lower than Japanese students.[40] On average, U.S. students generally did poorer than students from other countries.[41]

Several other studies that focus only on U.S. students have found a general decline in their performance in mathematics and science during the 1970s with some improvement in the 1980s.[42] These statistics suggest that the United States may have difficulty meeting the demand for the jobs associated with high-technology industries because these jobs require an increasingly high level of skill.

Table 4 shows the percentage of higher education degrees awarded to U.S. citizens and permanent U.S. residents that were awarded in science and engineering. The percentage of master's degrees and doctorates in science and

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[39] The participating countries were Belgium, Canada, England and Wales, Finland, France, Hong Kong, Hungary, Israel, Japan, Luxembourg, Netherlands, New Zealand, Nigeria, Scotland, Swaziland, Sweden, Thailand and the United States.

[40] The participating countries were Austrailia, Canada (English), England, Finland, Hong Kong, Hungary, Italy, Japan, South Korea, Netherlands, Norway, Philippines, Poland, Singapore, Sweden, Thailand and the United States.

[41] Unfortunately, only a small amount of research has occurred in this area. For a discussion of several other comparative studies, which reached similar conclusions, see National Science Board (1991), OECD (1992) and the November 21, 1992, issue of *The Economist*.

[42] See, for example, National Science Board (1991, 1989).

Table 4

Degrees Awarded to U.S. Citizens and U.S. Permanent Residents in the United States for Selected Years

	1977	1979	1981	1985	1987	1989	1990
Baccalaureate degrees in science and engineering as a percent of total	40.1	39.8	39.1	35.5	35.1	33.7	33.6
Science and engineering baccalaureate degrees awarded per 100,000 population	166.2	161.5	157.0	142.5	140.2	136.1	138.3
Total baccalaureate degrees awarded	912,484	913,487	924,246	961,619	974,940	1,003,714	1,035,598
Master's degrees in science and engineering as a percent of total	25.0	25.0	25.3	25.9	26.6	25.8	25.1
Per capita science and engineering master's degrees awarded per 100,000 population	34.1	31.4	30.2	28.2	28.6	28.9	28.9
Total master's degrees awarded	300,896	282,648	274,740	260,261	262,268	278,927	290,345
Doctorate degrees in science and engineering as a percent of total	53.2	54.0	54.8	56.2	56.6	57.7	57.2
Per capital science and engineering doctorate degrees awarded per 100,000 population	6.6	6.4	6.3	5.8	5.7	5.8	5.9
Total doctorate degrees awarded	27,487	26,784	26,342	24,694	24,561	25,024	25,844

SOURCE: National Science Foundation.

engineering being awarded has increased since 1977. On a per capita basis, however, the number of people getting bachelor's and advanced degrees, both in science and engineering and overall, has generally declined, although some improvement has occurred in the last three years.

Another factor that could play a pivotal role in determining the future of R&D investment in the United States is the recently proposed cuts in military spending. As previously discussed, defense-related expenditures on R&D in 1987 were responsible for 65.5 percent of government-funded R&D and 28.9 percent of total R&D in the United States, which is a significantly larger portion than allocated in other countries. Analysts are concerned that a loss of these funds could cause the U.S. share of global output in high technology to continue its decline. Of course, firms or the government could replace all of the military-funded R&D with other R&D funding.[43] A significant decline in R&D expenditure, however, would likely reduce U.S. innovation both absolutely and relative to other countries and could have an adverse effect on U.S. high-technology industries. Legislation has already been proposed in Congress to ensure government's commitment to R&D; one proposal uses defense-funded scientists to develop commercial technologies.[44] At this point, determining either the magnitude of any R&D cuts or the response of the nondefense government and private sectors to these cuts is essentially impossible.

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[43] For a study that examined the effect of a cut in federally financed R&D in the energy sector, see Mansfield (1984).

[44] See, for example, the National Defense Authorization Act (1992).

CONCLUSION

High-technology industries have a significant positive effect on economic growth because of their high rates of innovation. During the 1980s, production of high-technology products in OECD countries increased by 117 percent. The continued increase in resources devoted to R&D in Germany, Japan and the United States reflects the importance of high-technology industries. Although high-technology output as a percent of GDP has decreased somewhat in the United States during the last few years, it remains higher than it was in 1970. During this period, Japan and Germany, which initially spent a much smaller portion of GDP on R&D than did the United States, had significant growth in R&D expenditures and high-technology output. Thus although the commitment of resources for R&D relative to the size of each economy has essentially equalized in the three countries, the United States still spends the most in absolute terms on R&D and has the largest market share in high-technology industries. The extent to which the United States can exploit its size advantage depends on how productive U.S. R&D is relative to these other countries. Unfortunately, little research has been conducted on this topic, so although some experts have expressed concern about the productivity of U.S. R&D, evidence remains inconclusive. This important area of research has yet to be fully explored. Nevertheless, the increasing importance of high-technology industries suggests that a continued presence in these industries will help maintain high-wage/high-skill jobs and continued economic growth for the United States.

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