Volume Title: The American Economy in Transition

Volume Author/Editor: Martin Feldstein, ed.

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-24082-7

Volume URL: http://www.nber.org/books/feld80-1

Publication Date: 1980

Chapter Title: Technology and Productivity in the United States

Chapter Author: Edwin Mansfield, Ruben F. Mettler, David Packard

Chapter URL: http://www.nber.org/chapters/c11302

Chapter pages in book: (p. 563 - 616)

8 Technology and Productivity in the United States

1. Edwin Mansfield
2. Ruben F. Mettler
3. David Packard

1. Edwin Mansfield

8.1 Introduction

Technology consists of society's pool of knowledge concerning the industrial, agricultural, and medical arts. It is made up of knowledge concerning physical and social phenomena, knowledge regarding the application of basic principles to work in the relevant fields or professions, and knowledge of the rules of thumb of practitioners and craftsmen. Although the distinction between science and technology is imprecise, it is important. Science is aimed at understanding, whereas technology is aimed at use. At the outset, it is worth noting that changes in technology often take place as a consequence of inventions that depend on no new scientific principles. Indeed, until the middle of the nineteenth century, there was only a loose connection between science and technology.

The fundamental and widespread effects of technological change are obvious. Technological change has permitted the reduction of working hours, improved working conditions, provided a wide variety of extraordinary new products, increased the flow of old products and added a great many dimensions to the life of our citizens. Its contribution to American economic growth has been very important, as evidenced by Denison's (1962) estimate that about 40 percent of the total increase in national income per person employed during 1929–57 was due to "advance of knowledge."

Edwin Mansfield is professor of economics at the University of Pennsylvania.

My thanks go to Zvi Griliches and Richard Nelson, who commented on a preliminary draft of this paper.

At the same time, technological change also has its darker side. Advances in military technology have enabled modern nation-states to cause human destruction on an unprecedented scale; modern technology has contributed to various kinds of air and water pollution; and advances in industrial technology have sometimes resulted in widespread unemployment in particular occupations and communities. Despite the many benefits that society has reaped from technological change, no one would regard it as an unalloyed blessing. (For example, see National Commission on Technology, Automation, and Economic Progress [1966].)

8.2 Productivity Growth in the United States

Economists and policy makers have long been interested in productivity—the ratio of output to input. The simplest measure of productivity is output per hour of labor, often called labor productivity. Clearly, changes in labor productivity are of fundamental significance, since they are intimately related to, but by no means synonymous with, changes in a country's standard of living. The rate of technological change is one determinant of the rate of growth of labor productivity. Other important determinants of the rate of labor productivity growth are the extent to which capital is substituted for labor, economies of scale, changes in the utilization of productive capacity, and changes in the rate of diffusion of new techniques.

A somewhat more complicated measure of productivity is the total productivity index, which has the advantage that it takes account of both capital and labor inputs. Specifically, this index equals $q \div (zl + vk)$, where q is output (as a percentage of output in some base period), l is labor input (as a percentage of labor input in some base period), k is capital input (as a percentage of capital input in some base period), z is labor's share of the value of output in the base period, and v is capital's share of the value of the output in the base period. Substituting values of q, l, and k over a given period into this formula, one can easily calculate the value of the index for that period.

Labor productivity in the United States has not increased at a constant rate. The rate of growth of output per man-hour was significantly higher after World War I than before and significantly higher after World War II than before. Specifically, based on Kendrick's (1976) figures, the trend rate of growth of real output per man-hour was almost 2.5 percent for the three decades prior to 1948 (after adjustment for the effect of the Great Depression), as compared with over 3 percent from 1948 to 1973. This increase in the rate of growth of labor productivity seems to have been due to a faster increase in real capital per man-hour during 1948–73 than during 1919–48.

During 1966–79, however, there was a notable slowdown in the rate of increase of both output per man-hour and total productivity. Table 8.1 compares the rate of increase of productivity between 1966 and 1973 (both business-cycle peaks) with that during 1948–66. Output per man-hour increased by about 2.3 percent per year during 1966–73, as compared with 3.4 percent per year during 1948–66. Total productivity increased by less than 2 percent per year during 1966–73, as compared with 2.5 percent per year during 1948–66. In most industry divisions (and particularly in electric and gas utilities), there was a fall in the rate of increase of output per man-hour.

Since 1973 the rate of productivity increase in the United States has been even lower than during 1966–73. According to the Council of Economic Advisers (1979), output per man-hour increased by 1.0 percent during 1973–77, as compared with 2.3 percent during 1965–73. And between 1977 and 1978, it increased by only 0.4 percent. According to unpublished data that John Kendrick has made available to me, total productivity in manufacturing fell sharply from 1973 to 1974 and was only slightly higher in 1975 than in 1974. By 1976 it was not much above its 1973 value.

Table 8.1 Productivity Trends in the United States Private Domestic Economy, 1948–73

	Average Annual Percentage Rates of Change		
	1948–66	1966–69	1969–73[a]
Total Productivity	2.5	1.1	2.1
Real Product per Man-Hour:			
Private domestic economy	3.4	1.7	2.9
Agriculture	5.6	6.7	5.3
Mining	4.6	1.8	0.2
Contract construction	2.0	0	−0.5
Manufacturing	2.9	2.7	4.5
durable goods	2.8	2.2	—
nondurable goods	3.2	3.4	—
Transportation	3.7	2.2	4.5
Communications	5.5	4.6	4.1
Electric and gas utilities	6.1	4.4	1.0
Trade	2.9	2.1	2.3
wholesale	3.1	3.0	—
retail	2.7	1.0	—
Finance, insurance, and real estate	2.1	−0.4	0.2
Services	1.2	0.4	1.0

Source: Kendrick 1976.
[a]Preliminary.

What factors are responsible for this significant slackening of United States productivity growth? According to Kutscher, Mark, and Norsworthy (1977) of the Bureau of Labor Statistics, one of the major factors has been the increase in the proportion of youths and women in the labor force. Output per man-hour tends to be relatively low among women and among new entrants into the labor force. During the late 1960s, women and new entrants increased as a proportion of the labor force. Based on the Bureau's calculations, this change in labor force composition may have been responsible for 0.2 to 0.3 percentage points of the difference between the average rate of productivity increase in 1947–66 and that in 1966–73. George Perry (1971), in his analysis of the causes of the slowdown, agrees that this factor was important.

A second factor that has been cited in this regard is the rate of growth of the capital-labor ratio. During 1948–73, relatively high rates of private investment resulted in a growth of the capital-labor ratio (net nonresidential capital stock divided by aggregate hours worked in the private nonfarm sector) of almost 3 percent per year. After 1973, relatively low rates of investment resulted in the growth of the capital-labor ratio by only about 1.75 percent per year. According to the Council of Economic Advisers (1979), this reduction in the rate of growth of the capital-labor ratio may have reduced the rate of productivity increase by up to 0.5 percentage points per year. Christensen, Cummings, and Jorgensen (forthcoming), in their study of this topic, also emphasize the decrease in the rate of growth of the capital-labor ratio.

A third factor that has been cited in this regard is increased government regulation. A variety of new types of environmental, health, and safety regulations have been adopted in recent years. Because reduced pollution, enhanced safety, and better health are generally not included in measured output, the use of more of society's resources to meet these regulations is likely to result in a reduction in measured productivity growth. Also, the litigation and uncertainty associated with new regulations may discourage investment and efficiency, and the form of the regulations sometimes may inhibit socially desirable adaptations by firms. According to the Council of Economic Advisers (1979), the direct costs of compliance with environmental health and safety regulations may have reduced the growth of productivity by about 0.4 percentage points per year since 1973.

A fourth factor, cited by John Kendrick (1976) and others, is the reduction in the rate of increase of intangible capital due to the decrease in the proportion of gross national product devoted to research and development (R & D) during the late 1960s and early 1970s. In section 8.3 of this paper, we shall look closely at the changes over time in the level of R & D expenditures in the United States. For now, it is enough to say that United States R & D expenditures decreased, as a percentage of gross national product, from 3.0 percent in 1964 to 2.2 percent in 1978.

A fifth factor, cited by William Nordhaus (1972) and others, is the shift of national output toward services and away from goods. However, there is considerable disagreement over whether this shift in the composition of national output is responsible for much of the productivity slowdown. Michael Grossman and Victor Fuchs (1973), among others, are skeptical of this proposition.

Edward Denison (1978b) has carried out a particularly detailed investigation of the causes of the productivity slowdown. Table 8.2 shows his estimates of the sources of the growth of national income per person employed (NIPPE). According to these estimates, the advance of knowledge was responsible for 1.4 percentage points of the annual growth rate of NIPPE during 1948–69, and 1.6 percentage points of the annual growth rate of NIPPE during 1969–73. The effects of other factors, such as changes in the characteristics of the labor force, changes in

Table 8.2 **Sources of Growth of National Income per Person Employed, Nonresidential Business Sector**

Item	1948–69	1969–73	1973–76	Change from 1948–69 to 1973–76
Growth Rate of NIPPE	2.6	1.6	−0.5	−3.1
Effect of Irregular Factors	−0.1	−0.5	0.1	0.2
Adjusted Growth Rate	2.7	2.1	−0.6	−3.3
Changes in Labor Characteristics:				
Hours of work	−0.2	−0.3	−0.5	−0.3
Age-sex composition	−0.1	−0.4	−0.3	−0.1
Education	0.5	0.7	0.9	0.4
Changes in Capital and Land per Person Employed:				
Structures and equipment	0.3	0.2	0.2	−0.1
Inventories	0.1	0.1	0.0	−0.1
Land	0.0	−0.1	0.0	0.0
Improved Allocation of Resources[a]	0.4	0.1	0.0	−0.4
Changes in Legal and Human Environment[b]	0.0	−0.2	−0.4	−0.4
Economies of Scale	0.4	0.4	0.2	−0.2
Advances of Knowledge (and Not Elsewhere Classified)	1.4	1.6	−0.7	−2.1

Source: Denison 1978.

Note: Detail may not add to totals due to rounding.

[a]Includes only gains due to the reallocation of labor out of farming and out of self-employment in small nonfarm enterprises.

[b]Includes only effects on output per unit of input of costs incurred to protect the physical environment and the safety and health of workers, and of costs of crime and dishonesty.

capital and land per person employed, and economies of scale, are also estimated in table 8.2.

According to Denison, there was a sharp decline in NIPPE during 1974 and 1975. Such declines were without precedent in the period since World War II. Because of them, the 1973–76 rate of growth of NIPPE was negative (—0.5 percent). When the 1948–69 period is compared with the 1973–76 period, the adjusted rate of growth of NIPPE fell by 3.3 percentage points (from 2.7 percent to —0.6 percent). Denison's findings indicate that 0.4 percentage points of this decline were due to the use of more resources to meet pollution, safety, and health regulations (and to prevent crime). Another 1.2 percentage points of this decline were attributable to six factors: (1) a steeper drop in working hours, (2) an accelerated shift in the age-sex composition of employed labor, (3) a slower growth of fixed capital per worker, (4) a slower growth of inventories per worker, (5) reduced gain from resource reallocation, and (6) reduced gain from economies of scale. Of course, many of these factors have already been cited in earlier paragraphs of this section.

Denison concludes that 2.1 percentage points of the 3.3 point drop in the growth rate of NIPPE remain in the residual called "advances in knowledge and not elsewhere classified." To some extent, this may be due to a slowdown in the rate of technological change and in the rate of innovation. Much more will be said on this score in later sections of this paper. Also, the fact that 1974 and 1975 were the years when big oil price hikes first took effect suggests that their effects may be reflected in the residual. Some observers attribute a substantial proportion of the drop in the rate of productivity increase to the quadrupling of oil prices. Others, like Denison, do not seem to believe that this factor can explain a substantial portion of the decline in the growth rate of NIPPE. The truth is that there is considerable uncertainty regarding the contribution of various factors to the observed productivity slowdown.

8.3 Research and Development

Research and development, as defined by the National Science Foundation, includes activities of three kinds. First, there is basic research, which is "original investigation for the advancement of scientific knowledge . . . which do[es] not have immediate commercial objectives."[1] For example, an economist who constructs an econometric model, without any particular application in mind, is performing basic research. Firms carry out some basic research, but it is a small percentage of their R & D work. Second, there is applied research, which is research that is aimed at a specific practical payoff. For example, a project designed to determine the properties of a new polymer that a chemical firm plans to introduce would be applied research. The dividing line between basic and applied research is unclear at best. The distinction is based on the purpose of the project, applied research being done to promote specific practical and commercial aims, basic research being done to obtain new knowledge for its own sake.

Finally, there is development, which tries to reduce research findings to practice. Major development projects attempt to bring into being entirely new processes and products. Minor development projects attempt to make slight modifications of existing processes and products. Frequently, prototypes must be designed and constructed or pilot plants must be built. The dividing line between research and development often is hazy. Research is oriented toward the pursuit of new knowledge, whereas development is oriented toward the capacity to produce a particular product. The outcome of research is generally more uncertain than the outcome of development. Nonetheless, in development there often is considerable uncertainty regarding cost, time, and the profitability of the result.

To estimate the effects on aggregate output or productivity of the aggregate amount spent on R & D, economists have used econometric techniques to estimate the relationship between output, on the one hand, and labor, capital, and R & D, on the other. Results obtained during the 1960s provide reasonably persuasive evidence that R & D has had a significant effect on the rate of productivity increase in the industries that have been studied. Minasian (1969) and Mansfield (1968a) found that, in chemicals and petroleum, a firm's rate of productivity growth was directly related to its expenditures on R & D. Minasian's results indicated about a 50 percent marginal rate of return from R & D in chemicals. Mansfield's results indicated that the marginal rate of return from R & D was about 40 percent or more in the oil industry, and about 30 percent in chemicals if technical change was capital embodied (but much less if it was disembodied). In agriculture, Griliches (1964) found that, holding other inputs constant, output was related in a statistically significant way to the amount spent on research and extension. Evenson (1968), using time series data, estimated the marginal rate of return from agricultural R & D at about 57 percent.

More recently, Griliches (forthcoming), using data for almost nine hundred manufacturing firms, found that the amount spent by a firm on R & D was directly related to its rate of productivity growth. The private rate of return from R & D was about 17 percent (higher in chemicals and petroleum, lower in aircraft and electrical equipment). Terleckyj's (1974) findings suggest about a 30 percent rate of return from an industry's R & D based only on the effects on its own productivity. Also, his results show a very substantial effect of an industry's R & D on productivity growth in other industries. This, of course, is eminently reasonable since one industry's R & D often results in improved machines and inputs to be used by other industries.

Mansfield (1980) found that there is a direct relationship between the amount of basic research carried out by an industry or firm and its rate of productivity increase when its expenditures on applied R & D are held constant. Whether the relevant distinction is between basic and applied research is by no means clear: basic research may be acting to some extent as a proxy for long-term R & D. Holding constant the amount spent on applied R & D and basic research, an industry's rate of productivity increase during 1948–66 seemed to be directly related to the extent to which its R & D was long term.[2]

The National Science Foundation has published data for many years concerning the amount spent by industry, government, universities, and others on research and development. Table 8.3 shows total R & D expenditures in the United States from 1953 to 1979. Clearly, R & D expenditures grew very rapidly in the 1950s and early 1960s. In 1953 total R & D spending was about $5 billion, or about 1.4 percent of gross national product. By 1964 total R & D spending was about $19 billion, or about 3.0 percent of gross national product. Industry, impressed by the wartime accomplishments of science and technology, increased its R & D spending greatly. So did the federal government, which poured particularly large sums into defense and space R & D.

Table 8.3 Expenditures on Research and Development, United States, 1953–79 (Billions of Dollars)

Year	Total R & D Expenditures (Current Dollars)	Total R & D Expenditures (1972 Dollars)	Industry R & D Expenditures (1972 Dollars)	Government R & D Expenditures (1972 Dollars)
1953	5.1	8.7	3.8	4.7
1955	6.2	10.1	4.1	5.8
1957	9.8	15.1	5.3	9.4
1959	12.4	18.3	6.0	11.9
1961	14.3	20.7	6.9	13.4
1963	17.1	23.9	7.6	15.7
1965	20.1	27.0	8.8	17.5
1967	23.2	29.4	10.3	18.2
1969	25.7	29.6	11.5	17.2
1971	26.7	27.9	11.3	15.6
1973	30.4	28.8	12.2	15.5
1975	35.2	27.7	12.1	14.6
1977	42.9	28.2	12.9	14.3
1979[a]	52.4	32.0	15.1	15.8

Source: National Science Foundation 1976; 1977; 1979a.
[a]Preliminary estimate.

The industries that were the leading performers of R & D were aircraft and missiles, electrical equipment, chemicals, motor vehicles, and machinery. These industries accounted for over 80 percent of all R & D performed by industry in 1960, and they continued to do so in 1974. However, it is important to recognize that much of the R & D they performed was (and is) financed by the federal government. During 1964 the government financed about 90 percent of the R & D in the aircraft industry, about 60 percent of the R & D in the electrical equipment industry, about 25 percent of the R & D in the machinery and motor vehicles industries, and about 20 percent of the R & D in the chemical industry. Table 8.4 shows the intersectoral transfer of funds for R & D in 1976.

In the late 1960s, due partly to the tightening of federal fiscal constraints caused by the Vietnam War, federal expenditures on R & D (in 1972 dollars) decreased. From $18.2 billion in 1967, they fell to $14.5 billion in 1974. Much of this reduction was due to the winding down of the space program and the reduction (in constant dollars) of defense R & D expenditures. During 1975–78, there once again were increases in constant dollars in federal R & D expenditures. The biggest percentage increase occurred in expenditures for energy R & D, which increased (in current dollars) from $1.2 billion in 1975 to $2.9 billion in 1978.

Industry's expenditures on R & D (in 1972 dollars) increased during 1967–78 but at a much slower rate than in 1960–67. In 1960, industry's R & D expenditures (in 1972 dollars) were $6.6 billion; in 1967,

Table 8.4 **Intersectoral Transfers of Funds for Research and Development, United States, 1976 (Billions of Dollars)**

	Performers					
Sources of Funds	Federal Government	Industry	Universities and Colleges	FFRDCs[a]	Other Nonprofit Institutions	Total
Federal Government	5.6	10.2	2.5	1.1	0.8	20.2
Industry	—	16.3	0.1	—	0.1	16.5
Universities and Colleges	—	—	0.8	—	—	0.8
Other Nonprofit Institutions	—	—	0.3	—	0.3	0.6
Total	5.6	26.5	3.7	1.1	1.2	38.1

Source: National Science Foundation 1976.

[a]Federally funded research and development centers. These are organizations exclusively or substantially financed by the federal government to meet a particular requirement or to provide major facilities for research and training purposes. Those that are administered by industry (such as Oak Ridge National Laboratory or Sandia Laboratory) or nonprofit institutions (such as the Rand Corporation) are included in the respective totals for industry or nonprofit institutions.

they were $10.3 billion; in 1978, they were $14.1 billion. The slower rate of increase since 1967 may have reflected a stabilization or decline of the profitability of R & D. In the chemical and petroleum industries, Mansfield's (1979) results suggest such a change in the profitability of R & D. Also, Beardsley and Mansfield (1978) found, in a study of one of the nation's largest firms, that the private rate of return from its investments in new technology tended to be lower during the late 1960s and early 1970s than during the early 1960s.

The nation's total R & D expenditures (including government, industry, and others), when inflation is taken into account, remained essentially constant from 1966 to 1977. The constant dollar figures are very crude, since the National Science Foundation uses the GNP deflator to deflate R & D expenditures. But it seems to be generally accepted that no appreciable increase in real R & D expenditures took place during this period. As a percentage of gross national product, R & D expenditures fell from about 3.0 percent in 1964 to about 2.2 percent in 1978. This decline occurred almost continuously from 1964 to 1978, each year's percentage generally being lower than the previous year's.

Besides declining as a percentage of gross national product, R & D expenditures seem to have changed in character during the late 1960s and the 1970s. Mansfield (1979), in a survey of over one hundred firms accounting for about one-half of all industrial R & D expenditures in the United States, found that the proportion of company financed R & D expenditures devoted to basic research declined between 1967 and 1977 in practically every industry (Nason, Steger, and Manners 1978 came to essentially the same conclusion). In the sample as a whole, the proportion fell about one-fourth, from 5.6 percent in 1967 to 4.1 percent in 1977.

In four-fifths of the industries, based on a rough measure of the perceived riskiness of projects, there was also a decline between 1967 and 1977 in the proportion of R & D expenditures devoted to relatively risky projects. In metals, chemicals, aircraft, drugs, and rubber this reduction was quite large. In some industries, such as aircraft, chemicals, metals, and rubber there was also a substantial decline in the proportion of R & D expenditures devoted to relatively long-term projects. But in other industries, such as drugs, there was an increase in this proportion.

When asked why they reduced the proportion of their R & D expenditures going for basic research and relatively risky projects, the reason most frequently given by the firms was the increase in government regulations, which they felt had reduced the profitability of such projects. Another reason was that breakthroughs were more difficult to achieve than in the past, because the field has been more thoroughly worked over. Still another reason, emphasized by Nason, Steger, and Manners (1978), is that management has changed its view of how R & D should be managed. In the 1950s and early 1960s, firms frequently did not try to manage R & D in much detail. When some of the results turned out to be disappointing, many firms began to emphasize control, formality in R & D project selection, and short-term effects on profit. The shift in emphasis has tended to reduce the proportion of R & D expenditures going for basic and risky projects. Although there is general agreement that a greater emphasis on detailed management was justified, many observers wonder whether the pendulum may have swung too far.

8.4 Scientific and Engineering Personnel

Engineers and scientists, although they are by no means the sole source of advances in technology, play an important role in bringing about such advances and in fostering their utilization and acceptance. Since World War II, there have been three quite distinct periods with regard to the employment of engineers and scientists. The first period, from about 1950 to 1963, was marked by rapid growth of jobs for engineers and scientists. As shown in table 8.5, the employment of engineers and scientists grew by over 6 percent per year, which was far in excess of the rate of growth of total nonfarm employment. In part, this rapid increase was due to increases in defense activities and in the space program. During this period there were many complaints of a shortage of engineers (see Cain, Freeman, and Hansen 1973 and Hansen 1967).

The second period, from about 1963 to 1970, saw the employment of engineers and scientists grow at about the same rate as total nonfarm employment. The employment of scientists grew more rapidly than the employment of engineers, because there was a relatively rapid increase in college enrollments and research programs. The relatively slow rate of increase of engineering employment reflected cutbacks in defense programs and space exploration, among other things.

The third period, from about 1970 to 1974, was marked by a very slow growth of scientific and engineering employment. Whereas total

Table 8.5 **Average Annual Percentage Change in Scientific, Engineering, and Total Nonfarm Employment, 1950–63, 1963–70, and 1970–74**

Type of Employment	1950–63	1963–70	1970–74
Scientists	7.0	4.8	1.4
Engineers	6.5	2.5	0.3
Scientists and Engineers	6.6	3.2	0.7
Nonfarm Wage and Salary Workers	1.7	3.3	2.5

Source: National Science Foundation 1977.

nonfarm employment grew by 2.5 percent per year, the employment of engineers and scientists grew by 0.7 percent per year. (Indeed, between 1970 and 1972, there was a decline of twenty thousand persons in engineering employment.) In considerable part, this was due to a slower growth (or curtailment) of college enrollment, R & D expenditures, and defense activities—particularly in aircraft and related products.

Unemployment rates for scientists and engineers have tended to be very low. During the 1960s, the unemployment rate for these workers was below 1 percent. But in 1971, due partly to the cutbacks in defense spending and some R & D programs, the unemployment rate for scientists and engineers rose to about 3 percent. By 1973, it fell below 1 percent once again. However, in 1975, the unemployment rate for engineers increased to 2.6 percent, due to the recession.

Most engineers and scientists are employed by industry. Over one million were employed in the industrial sector in the mid-1970s, as compared with about three-hundred thousand in universities and colleges,and about two-hundred thousand in the federal government. Table 8.6 shows the allocation of industry's labor force among various work activities. About 37 percent of the scientists and 26 percent of the engineers are involved in R & D or R & D management. However, this does not mean that the others do not play an important role in the process by which technology is developed and applied. The interface between R & D and the rest of the firm is of fundamental importance in determining the rate of innovation, as Freeman (1974), Mansfield et al. (1977a), and others have indicated. Production engineers, sales engineers, and other non-R & D engineers and scientists play a significant part in the innovation process.

An important characteristic of the nation's engineers is their age. Many studies suggest that engineers, particularly those engaged in research and development, tend to experience a reduction in creativity

Table 8.6 **Percentage Distribution of Industry's Scientific and Engineering Labor Force, by Primary Work Activity, 1974**

Primary Work Activity	Scientists	Engineers	Scientists and Engineers
R & D and R & D Management	37	26	29
Management of Non-R & D Activities	15	20	19
Production and Inspection	13	17	16
Design	1	18	14
Computer Applications	19	2	6
Other Activities	15	17	16
Total	100	100	100

Source: National Science Foundation 1977.

after the age of thirty-five or forty, due in part to obsolescence of knowledge. Given the slowdown in the rate of growth of the engineering labor force, one would expect that the proportion of engineers that are young has declined. To see how big this decline has been, Brach and Mansfield (1979) obtained detailed data from six major firms in the aerospace, chemical, and petroleum industries. The results show that the percentage of engineers under thirty-four years decreased from 51 percent in 1960 to 30 percent in 1974, and that the percentage under forty-three years decreased from 78 percent in 1960 to 56 percent in 1974. When the sample was expanded to include eighteen firms in the aerospace, electronics, chemical, and petroleum industries, similar results were obtained. If, as some claim, the rate of innovation in the United States has been slowing down, it is conceivable that this "graying" of industry's engineers may be partly responsible.

Given the slowdown in the demand for engineers, it is not surprising that the percentage of bachelor's (and first professional) degrees awarded in engineering declined continually and significantly between 1960 and 1975. In 1960, engineering degrees were 10 percent of the total; in 1975, they were 4 percent of the total. The percentage of bachelor's (and first professional) degrees in the physical and environmental sciences fell from 4 percent in 1960 to 2 percent in 1975. (In contrast, the percentage in the social sciences increased from 8 percent in 1960 to 14 percent in 1975.) Turning from undergraduates to graduate students, enrollments for advanced degrees in science and engineering decreased from 38 percent of all advanced degree enrollment in 1960 to 25 percent in 1975. And according to the National Science Foundation (1979c), a sizable proportion of the doctoral labor force in science and engineering may have to obtain jobs outside science and engineering in 1982 and 1987.

8.5 Patents and Innovations

The number of patents is sometimes used as a crude index of the rate of invention in a given field during a particular period of time. Used in this way, patent statistics have important disadvantages. For one thing, the average importance of the patents granted at one time and place may differ from those granted at another time and place. For another, the proportion of the total inventions that are patented may vary significantly. Nonetheless, it is worthwhile examing the patent statistics at least briefly.

Table 8.7 shows the changes over time in the number of United States patents granted. The number of patents granted to United States residents rose during the 1960s, reached a peak in 1971, and was about 20 percent lower in 1976 than in 1971. When patents are broken down by

Table 8.7 United States Patents Granted to United States Residents, by Year of Grant, 1960–76

Year	Number of Patents (Thousands)	Year	Number of Patents (Thousands)
1960	39.5	1969	50.4
1961	40.2	1970	47.1
1962	45.6	1971	56.0
1963	37.2	1972	51.5
1964	38.4	1973	51.5
1965	50.3	1974	50.6
1966	54.6	1975	56.7
1967	51.3	1976	44.3
1968	45.8		

Source: National Science Foundation 1977.

product field, the results are much the same. For example, the number of patents on electrical equipment, instruments, and communication equipment all reach a peak in 1971. In some product fields, such as machinery and fabricated metals, the peak is reached in the late 1960s. In chemicals, it is reached in 1972. One problem with the data in table 8.7 is that they are influenced by changes over time in how rapidly patent applications are processed.

The number of patents granted is a measure of inventive activity in a previous period, since roughly two years are taken by the Patent Office to process and examine a patent application. To correct for this, table 8.8 shows the number of patents by year of application. There is much less year-to-year fluctuation in the number of patents when application dates rather than grant dates are used. And, as would be expected, the peak patenting rate now occurs in 1969 rather than 1971. When the data are broken down by product field, the results are surprisingly uniform. In machinery, fabricated metals, and electrical equipment, the peak is in 1966; in communication equipment and chemicals, it is in 1969; and in instruments, it is in 1971. In practically all of the fifty-two product fields for which data are available, the patent rate declined during the 1970s. The only exceptions are in drugs, agricultural chemicals, and motorcycles, bicycles, and parts.

From the economist's point of view, innovation is often more relevant than invention. Innovation is generally defined as the first commercial introduction of a new or improved process or product. The rate of innovation depends heavily on the quality of a nation's industrial managers and the way its firms and industries are organized, as well as on the tax laws, regulatory considerations, and a host of other factors influencing the profitability and riskiness of innovative activity. Successful innovation requires a great deal more than the establishment of an R & D laboratory that turns out a lot of good technical output. In many industries, the bulk of the innovations are not based to any significant extent on the firms' R & D. And even in those industries where R & D is important, one of the crucial problems is to effect a proper coupling between R & D, on the one hand, and marketing and production, on the other. Unless this coupling is effective, R & D can be of little use.

To measure the rate of innovation, counts have sometimes been made of the number of major new processes or products introduced in particular periods of time. For example, in the pharmaceutical industry, the number of new chemical entities per year is often used for this purpose. Measures of this sort have important problems. For one thing, it frequently is difficult to find suitable weights for different innovations. (Clearly, all are not of equal importance.) For another thing, such measures overlook the small innovations, which sometimes have a bigger cumulative effect than some of the more spectacular innovations. (For evidence on this score in petroleum and synthetic fibers, see Enos 1958 and Hollander 1965.) Nonetheless, it is worthwhile taking a brief look at results based on data of this sort.

In the pharmaceutical industry, the number of new chemical entities per year (excluding salts or esters of previously marketed drugs) declined from an average of about forty during the 1950s to about twenty during the 1950s to about fifteen during the early 1970s. This decline

Table 8.8 United States Patents Due to United States Inventors, by Year of Application, 1965–73 (Thousands of Patents)

	1965	1966	1967	1968	1969	1970	1971	1972	1973
All Patents	42.2	45.0	44.1	45.3	46.3	45.6	45.3	41.9	41.6
Food	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.4	0.4
Textiles	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.4	0.3
Chemicals	5.8	6.2	6.1	6.1	6.3	6.2	6.1	5.4	4.9
Drugs	0.6	0.7	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Oil and Gas	0.6	0.7	0.7	0.8	0.8	0.8	0.7	0.6	0.6
Rubber	2.3	2.4	2.4	2.3	2.5	2.3	2.3	2.2	1.8
Stone, Clay, and Glass	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.0	0.9
Primary Metals	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5
Fabricated Metals Products	5.8	6.4	6.2	6.2	6.2	6.1	6.0	5.6	5.1
Machinery	13.3	14.3	13.8	14.0	14.2	13.9	13.9	12.7	11.7
Electrical Equipment	4.8	5.3	5.1	5.2	5.1	5.1	4.8	4.5	4.3
Communications and Electronics	5.2	5.4	5.1	5.2	5.7	5.5	5.3	5.0	4.7
Transportation Equipment	2.2	2.6	2.5	2.7	2.6	2.6	2.7	2.5	2.5
Aircraft	0.5	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7
Instruments	4.5	4.6	4.7	4.8	5.0	5.1	5.2	4.8	4.7

Source: National Science Foundation 1977.
Note: Most of these patents were assigned to United States corporations.

has caused considerable controversy. The drug industry charges that it is due in considerable measure to new government regulations. Others attribute it, at least in part, to the fact that the field is more thoroughly worked over than it was shortly after World War II, and that it has become increasingly difficult and costly to make major advances. As pointed out by Grabowski (1976) and others, available estimates indicate very substantial increases during the 1960s in the costs of developing a new drug.

Counts of innovations have also been used to indicate changes over time in the nature of major innovations introduced by United States firms. The National Science Foundation (1977) reports a study of 277 major innovations marketed by United States manufacturing firms that tried to rate how radical each innovation was. In 1953–59, 36 percent of the innovations were rated as radical breakthroughs (rather than as major technological shifts, improvements, or imitations), as contrasted with 26 percent in 1960–66 and 16 percent in 1967–73. Although the results are of interest, ratings of this sort should be viewed with considerable caution.

8.6 The Diffusion of Innovations

How rapidly productivity increases in response to an innovation depends on the rate of diffusion—the rate at which the use of the innovation spreads. Diffusion, like the earlier stages in the creation and assimilation of new techniques and products, is essentially a learning process. However, instead of being confined to a research laboratory or a few firms, the learning takes place among a considerable number of users and producers. In the United States, how rapidly does the diffusion process go on? According to the available data, it takes about five to ten years, on the average, before one-half of the major firms in an industry begin using an important technique. And in many cases it takes longer. The rate of imitation varies widely (Mansfield 1968b).

To explain the differences among innovations in the rate of imitation, Mansfield (1968a) suggested a simple model that assumes that the probability that a nonuser will use the innovation between time t and time $t+1$ is dependent on the proportion of firms already using the innovation, the profitability of using the innovation, and the investment required to install the innovation. Mansfield tested this model against data for over a dozen innovations in five industries, the results being quite favorable. Hsia (1973) found that this model provides a good fit to data regarding twenty-six innovations in the plastics, textiles, and electronics industries in Hong Kong. Blackman (1971) found this model to be useful in his studies of the United States aircraft industry. Romeo used a variant of this model in his study (in Mansfield et al. 1977a) of numerically controlled machine tools.

To indicate more specifically how rapidly some major innovations have spread in the period since World War II, table 8.9 shows the increase over time in the percentage of (1) steel output produced by the basic oxygen process, (2) ammonia capacity accounted for by large-scale plants (600 tons per day or more), (3) acrylonitrile output produced from propylene, (4) vinyl chloride capacity that uses the oxychlorination process, and (5) value of discrete semiconductors and receiving tubes accounted for by discrete semiconductors. On the average, it took about eight years before half of the output or capacity was accounted for by these innovations.

At least two studies have been made which shed light on whether or not innovations spread more rapidly than they used to. First, when the

Table 8.9 Rates of Diffusion of Five Major Innovations in the United States

Year	% Steel Produced by Basic Oxygen Process	% United States Ammonia Capacity: Large-Scale Plants	% Acrylonitrile Produced from Propylene	% Vinyl Chloride Capacity Using Oxychlorination	Discrete Semiconductor Output as Percentage of Output of Semiconductors and Receiving Tubes
1953	—	—	—	—	7.4
1954	—	—	—	—	8.0
1955	—	—	—	—	9.5
1956	—	—	—	—	18.8
1957	—	—	—	—	27.4
1958	1.6	—	—	—	—
1959	2.0	—	—	—	51.4
1960	3.4	—	9.1	—	60.9
1961	4.0	—	11.2	—	63.3
1962	5.6	—	15.3	—	64.2
1963	7.8	—	22.0	—	68.2
1964	12.2	—	32.6	—	71.5
1965	17.4	2.5	46.0	32.0	76.1
1966	25.3	6.2	59.5	40.0	79.0
1967	32.6	20.1	86.0	—	81.4
1968	37.1	41.7	88.9	56.0	82.3
1969	42.6	58.3	89.7	70.0	—
1970	48.2	58.8	94.7	—	—
1971	53.1	63.1	100.0	81.0	—
1972	56.0	—	—	83.0	—
1973	55.2	—	—	—	—
1974	56.0	79.2	—	—	—

Source: Mansfield 1977.

profitability of the innovation and the size of the investment required to introduce the innovation are held constant in Mansfield's study, there is an apparent tendency for the rate of diffusion to increase over time. However, this tendency was very weak. The time interval between 20 percent adoption and 80 percent adoption decreased, on the average, by only about four-tenths of 1 percent per year. Further, this observed tendency could easily have been due to chance.

Second, in the case of chemicals, a study (reported in Mansfield et al. 1977a) of the diffusion of twenty-three major processes was carried out by Simon. His results indicate that an innovation's rate of diffusion is affected by the profitability of the innovation to users and by whether or not the firms that imitated the innovator used its process or invented around it. Holding both of these variables constant, there is a tendency for the rate of imitation to be higher for more recent innovations. Moreover, this tendency is statistically significant. Also, holding other factors constant, there seems to be a tendency for new chemical products to be imitated more rapidly than was the case a number of years ago.

Thus, what evidence we have points to an acceleration, rather than a slowdown, in the rate of diffusion. In part, this has probably been due to the growth of more effective mechanisms to transmit and evaluate technical information. For example, the engineering literature is more extensive and detailed, and evaluation techniques are more sophisticated. Turning to international comparisons, the United States seemed to be a leader in accepting some of the innovations in table 8.9. For example, this was the case for semiconductors. But with respect to the basic oxygen process in steel, a number of other countries had a faster rate of acceptance than the United States.

8.7 America's Technological Lead

To understand the changes in America's technological position in the postwar period, it is necessary to compare United States technological capabilities with those in other countries. Based on international comparisons of total productivity and on data indicating which countries have developed and exported new and improved products, there appears to have been a substantial gap between European and American technology. Thus, Denison (1967) concluded that productivity differences between Europe and the United States could not be explained fully by differences in capital per worker, education, or other such variables. And Vernon (1966) and Hufbauer (1970) have demonstrated that, to a large extent, American exports have been in new products which other countries have not yet produced.

This gap does not seem to be new. The available evidence, which is fragmentary, suggests the existence of such a gap in many technological areas prior to 1850. After 1850, total productivity seemed higher in the United States than in Europe, the United States had a strong export position in technically progressive industries, and Europeans tended to imitate American techniques. American inventors were enormously productive during the nineteenth century, and the United States held a technological lead in many major areas of manufacturing.

The technology gap received considerable attention in the 1960s, when many Europeans claimed that superior technology had permitted American firms to get large shares of European markets in such areas as aircraft, space equipment, computers, and other electronic products. In response to the Europeans' concern, the Organization for Economic Cooperation and Development (OECD) carried out a major study (1968) of the nature and causes of the technology gap. The study concluded that a large gap existed in computers and electronic components, but that no general or fundamental gap existed in drugs, bulk plastics, iron and steel, machine tools (other than numerically controlled machine tools), nonferrous metals (other than tantalum and titanium), and scientific instruments (other than electronic test and measuring instruments).

The longstanding technological lead enjoyed by the United States has undoubtedly been due to a variety of factors—such as the favorable social and business climate in the United States, our competitive system, and the values of the American people. According to the OECD studies, the size and homogeneity of the United States market has been an important factor but not a decisive one. Also, the bigness of American firms is considered to be another factor but not a decisive one. Further, the large government expenditures on R & D in the United States have been credited with an important role. In addition, according to the OECD studies, American firms have had a significant lead in managerial techniques, including those involved in managing R & D and in coupling R & D with marketing and production.

More recently, American analysts and policy makers have expressed increasing concern that the United States technological lead is being reduced and in some areas eliminated. At least three types of evidence have been adduced. First, as shown in table 8.10, the percentage increase in American labor productivity has been smaller than in Japan, Germany, France, or the United Kingdom. In Japan, output per man-hour grew by 290 percent during 1960–76, as compared with about 60 percent in the United States. Christenson, Cummings, and Jorgenson (forthcoming) have estimated that the rate of increase of total productivity during 1960–73 was lower in the United States than in Canada, France, Germany, Italy, Japan, Korea, the Netherlands, or the United Kingdom. Although the level of productivity in other countries still tends to be lower than in the United States, results of this kind have been interpreted as evidence of a decline in the American technological lead.

Table 8.10 **Output per Man-Hour in Manufacturing, Selected Countries, 1960–76 (1967 = 100)**

Country	1960	1962	1964	1966	1968	1970	1972	1974	1976
United States	78.8	84.5	95.2	99.7	103.6	104.5	116.0	114.7	122.4
France	68.7	75.2	83.7	94.7	111.4	121.2	135.9	146.1	153.6
Germany	66.4	74.4	84.5	94.0	107.6	116.6	130.3	145.6	162.4
Japan	52.6	61.9	75.9	87.1	112.6	146.5	163.9	187.5	204.6
United Kingdom	76.8	79.3	89.7	95.7	106.9	109.1	121.2	127.9	125.4
Canada	75.5	83.9	90.9	97.2	107.3	115.2	127.4	132.3	137.4

Source: National Science Foundation 1977.

Second, as shown in table 8.11, R & D expenditures as a percentage of gross national product have increased in Japan, Germany, and the Soviet Union, while they have decreased in the United States. But this evidence should be treated with caution. Although the percentage of gross national product devoted to R & D has increased in these countries relative to the United States, the United States percentage is still higher than any country other than the Soviet Union, where the figures are not comparable (and probably inflated relative to ours). Also, as we shall see in the following section of this paper, much of the industrial R & D in some major foreign countries is done by United States-based multinational firms. One-half of the industrial R & D in Canada and one-seventh of the industrial R & D in Germany and the United Kingdom were carried out by United States-based firms in the early 1970s. And more fundamentally, a nation's rate of economic growth depends on how effectively it uses both foreign and domestic technology, and this may not be measured at all well by its ratio of R & D spending to gross national product.

Third, the National Science Foundation (1977) has reported a study which indicates that the United States originated about 80 percent of

Table 8.11 **Expenditures on R & D as a Percentage of Gross National Product, Selected Countries, 1961–75**

Country	1961	1963	1965	1967	1969	1971	1973	1975
United States	2.74	2.87	2.92	2.91	2.75	2.50	2.33	2.32
France	1.38	1.53	1.99	2.16	1.96	1.87	1.73	1.48
Germany	—	1.40	1.72	1.97	2.02	2.36	2.22	2.25
Japan	—	—	1.55	1.55	1.71	1.88	1.92	—
United Kingdom	2.69	—	—	2.69	2.63	—	—	—
Canada	1.01	0.95	1.17	1.33	1.34	1.25	1.11	—
USSR	—	2.37	2.40	2.55	2.62	2.85	3.19	3.18

Source: National Science Foundation 1977.

the major innovations in 1953–58, about 67 percent of the major innovations in 1959–64, and about 57 percent of the major innovations in 1965–73. Without knowing more about the way in which the sample of innovations was drawn, it is hard to tell whether the apparent reduction in the proportion of innovations stemming from the United States is due to the sampling procedures. Also, some attempt might have been made to weight these innovations. Nonetheless, taken at face value, the results suggest a reduction in the United States technological lead.

8.8 International Technology Transfer

In recent years, the international transfer of technology has become of intense interest to analysts and policy makers. A firm can use various channels to transfer its new technology abroad. It can export goods and services that are based on the new technology. Or it can use the new technology in foreign subsidiaries. Or it can license the new technology to other firms, government agencies, or other organizations that utilize it abroad. Or it can engage in joint ventures with other organizations, which have as an objective the utilization of the new technology abroad.

International technology transfer accounts for a substantial proportion of the returns from R & D carried out by United States firms. Based on a study of thirty major firms, Mansfield, Romeo, and Wagner (1979) found that about 30 percent of the returns from these firms' 1974 R & D were expected to come from foreign sales or foreign utilization. During the first five years after the commercialization of the technology, foreign subsidiaries (rather than exports, licensing, or joint ventures) were expected to be the principal channel of transfer in about 70 percent of the cases (table 8.12). This is noteworthy because, according to the tradi-

Table 8.12 Percentage Distribution of R & D Projects, by Anticipated Channel of International Technology Transfer, First Five Years after Commercialization, Twenty-three Firms, 1974

	Channel of Technology Transfer				
Category	Foreign Subsidiary	Exports	Licensing	Joint Venture	Total
All R & D Projects:					
Sixteen industrial firms	85	9	5	0	100
Seven major chemical firms	62	21	12	5	100
Projects Aimed at:					
Entirely new product	72	4	24	0	100
Product improvement	69	9	23	0	100
Entirely new process	17	83	0	0	100
Process improvement	45	53	2	1	100

Source: Mansfield, Romeo, and Wagner 1979.

tional view, the first channel of international technology transfer often is exports. Only after the overseas market has been supplied for some time by exports would the new technology be transferred overseas via foreign subsidiaries according to this view.

To some extent, these results seem to reflect an increased tendency for new technology to be transferred directly to overseas subsidiaries, or a tendency for it to be transmitted more quickly to them (in part because more such subsidiaries already exist). Such tendencies have been noted in the drug industry, where many new products developed by United States drug firms have been introduced first by their subsidiaries in Britain and elsewhere. Also, Baranson (1976), based on twenty-five case studies, concludes that American firms of various types are more willing than in the past to send their most recently developed technology overseas. And Davidson and Harrigan (1977) have shown that United States firms introduce their new products in foreign markets much sooner than they used to (table 8.13), and that foreign subsidiaries are used more frequently (and licensing is used less frequently) as a channel of transfer than used to be true.

Mansfield and Romeo (in press) gathered data concerning sixty-five technologies to see whether the proportion of transferred technologies that were less than five years old (at the time of transfer) was greater during 1969–78 than during 1960–68. For technologies transferred to subsidiaries in developed countries, this was the case, and the increase in this proportion (from 27 percent in 1960–68 to 75 percent in 1969–78) was both large and statistically significant. But for technologies transferred to subsidiaries in developing countries or for those transferred through channels other than subsidiaries, there appeared to be no such tendency, at least in this sample. The fact that the technologies licensed to, or jointly exploited with, non-United States firms were no newer in 1969–78 than in 1960–68 is worth noting, since some observers

Table 8.13 **Percentage of New Products Introduced Abroad within One and Five Years of Introduction in the United States, 1945–75**

Period	Number of New Products	Percentage Introduced Abroad	
		Within One Year	Within Five Years
1945–50	161	5.6	22.0
1951–55	115	2.6	29.6
1956–60	134	10.4	36.6
1961–65	133	24.1	55.6
1966–70	115	37.4	60.1
1971–75	75	38.7	64.0

Source: Davidson and Harrigan 1977.

worry that United States firms may have come to share in this way more and more of their newest technologies with foreigners.

In general, the evidence suggests that the rate of international diffusion of technology has tended to increase. Because of better communication and transportation techniques, as well as other factors, such an increase is quite understandable. Cooper (1972) has presented some evidence to this effect. Also, the OECD studies (1968) of the technology gap come to the same conclusion. One of the most recent studies of this topic was by Schwartz (1979), who investigated the international diffusion of fifteen plastics innovations, thirteen semiconductor innovations, and nine drug innovations. Holding other factors constant, he found that the diffusion rate tended to be higher for more recent innovations in each industry, although this tendency was statistically significant only in plastics.

According to the National Science Foundation (1977), data concerning United States receipts and payments of licensing fees and royalties can be used as an indicator of the amount of know-how transferred by the United States, as well as the direction of the technology flows. Tables 8.14 and 8.15 present the latest data published by the National Science Foundation. According to these figures, the United States received about $3.5 billion from foreign affiliates and about $800 million from unaffiliated foreign residents in 1975, and paid about $200 million to foreign affiliates and about $200 million to unaffiliated foreign residents. Based on tables 8.14 and 8.15, American receipts and payments of this sort more than tripled during 1966–75, and those to unaffiliated foreign residents more than doubled during this period.

These figures, while interesting, suffer from many defects. For one thing, payments of this sort between affiliated firms are influenced by tax and other considerations. For another, much technology is transferred internationally without payment because the technology is not patented, because firms in one country copy (without payment) features of new products or processes originating in another country, and so on. Nonetheless, tables 8.14 and 8.15 can be used to support at least two important propositions. First, it seems clear that the international transfer of technology is a large and rapidly growing business. Second, it seems clear that multinational firms play a very important role in the international transfer of technology.

Studies by Baranson (1976), Caves (1971), Hufbauer (1970), OECD (1968), Tilton (1971), and others show in much more detail the major role played by multinational firms in the international transfer of technology. As would be expected, the preponderant flow of technology has been out of the United States. In recent years, with the trend toward increased foreign direct investment in the United States, some observers have worried that such investment might result in foreign firms gaining

Table 8.14 **United States Receipts and Payments of Royalties and Fees for Unaffiliated Foreign Residents, 1966–75 (United States Dollars in Millions)**

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975 (preliminary)
Net Receipts										
Total	353	393	437	486	573	618	655	712	751	759
Developed countries	304	342	375	426	505	547	575	633	646	644
Western Europe	186	190	196	222	247	268	270	297	321	343
Canada	30	33	31	28	33	32	38	32	38	37
Japan	70	95	130	155	202	223	240	273	249	227
Other developed countries[a]	18	24	18	21	23	24	27	31	38	37
Developing countries	50	50	59	59	64	62	72	74	94	105
Eastern Europe		1	4	2	4	9	8	5	11	9
Net Payments										
Total	76	104	106	120	114	123	139	176	186	192
Developed countries	72	100	102	116	107	119	134	166	176	184
Western Europe	67	93	94	107	99	110	121	146	156	168
Canada	2	3	4	4	4	5	6	6	7	7
Japan	3	4	4	4	4	4	6	13	12	8
Developing countries	4	3	4	5	7	4	5	9	8	7
Eastern Europe							1	1	2	1

Source: National Science Foundation 1977.

Note: Table represents receipts and payments between United States residents with residents or governments of foreign countries for the use of intangible property such as patents, copyrights, or manufacturing rights. Excludes fees and royalties related to United States foreign direct investments. Excludes film rentals.

[a]Other developed countries included here are Australia, New Zealand, and the Republic of South Africa.

Table 8.15 **United States Receipts and Payments of Royalties and Fees for Direct Investment Abroad, 1966–75 (United States Dollars in Millions)**

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975 (preliminary)
Net Receipts[a]										
Total	1,162	1,354	1,431	1,533	1,758	1,927	2,115	2,513	3,071	3,526
Developed countries	854	982	1,027	1,101	1,289	1,429	1,609	1,949	2,389	2,740
Western Europe	496	579	594	651	755	848	971	1,180	1,428	1,722
Canada	246	266	285	287	336	355	377	416	541	566
Japan	43	55	59	66	80	96	114	170	211	231
Other developed countries[b]	69	83	88	97	118	131	147	183	209	221
Developing countries	279	352	377	398	428	452	453	519	631	734
International and unallocated	29	20	27	34	40	46	53	46	51	52
Net Payments[c]										
Total	64	62	80	101	111	118	155	209	212	241
Canada	41	43	47	56	62	64	60	73	83	89
United Kingdom	12	11	21	25	19	11	15	20	16	10
Other European countries	10	8	9	16	23	39	78	113	111	140
Other countries	1	1	3	4	7	4	2	2	2	1

Source: National Science Foundation 1977.

[a]Represents net receipts of payments by U.S. firms from their foreign affiliates for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, and management ties.

[b]Other developed countries included here are Australia, New Zealand, and the Republic of South Africa.

[c]Payments measure net transactions between U.S. affiliates and their foreign patents. Affiliated payments are not further detailed because in many cases the amounts are too small or would disclose individual company data.

access to important United States technology. According to the National Academy of Engineering (1976), access to American technology is less important than many other factors in prompting such investment.

Another important development in the postwar period has been the growth of overseas R & D by United States-based multinational firms. During the 1960s and early 1970s, the percentage of total company-financed R & D expenditures carried out overseas grew substantially. By the middle 1970s, it had risen to almost 10 percent. (Table 8.16 presents data for fifty-five firms.) According to Mansfield, Teece, and Romeo (1979), much of this R & D is aimed at the special design needs of overseas markets. It tends to be predominantly development rather than research, and aimed at product and process modification rather than at entirely new products or processes.

Firms differ considerably in the extent to which they have integrated their overseas R & D with their domestic R & D. Some firms, such as the IBM Corporation, have integrated their R & D activities on a worldwide basis. Such worldwide integration existed in about half of the firms studied by Mansfield, Teece, and Romeo. Most overseas R & D seems to have some commercial applicability to the firms' United States operations. According to the firms studied by Mansfield, Teece, and Romeo, a dollar's worth of overseas R & D seems to result in benefits to these firms' domestic operations that are equivalent to about fifty cents of R & D carried out in the United States.

Some groups, such as the AFL-CIO, have pressed for measures to regulate the international transfer of technology to prevent our advanced technology from becoming available to competitors in other nations. Thus, in 1971, the AFL-CIO suggested that "the President [be given] clear authority to regulate, supervise, and curb licensing and patent agreements on the basis of Congressionally determined standards."[3] Economists generally seem to have been rather skeptical of such proposals to interfere with the international diffusion of technology. It would be very difficult to stem the diffusion of technology, and even if it could be done, it would invite retaliation. Technology flows both into and out of the United States, and there are mutual benefits from international specialization with respect to technology.

Table 8.16 **Percentage of Company-Financed R & D Expenditures Carried out Overseas, 1960–74, Fifty-five Firms**

	1960	1965	1970	1972	1974
Thirty-five-Firm Subsample	2	6	6	8	10
Twenty-Firm Subsample	—	—	4	—	9

Source: Mansfield, Teece, and Romeo 1979.

In addition, if United States firms could not transfer and utilize their technology abroad, they would not carry out as much research and development, with the result that our technological position would be weakened. According to results obtained by Mansfield, Romeo, and Wagner (1979), public policy makers should not assume that decreased opportunities for international technology transfer would have little or no effect on United States R & D expenditures. On the contrary, if United States firms could not transfer their new technology to their foreign subsidiaries, the result might well be a 10 or 15 percent drop in their R & D expenditures.

Some groups have also pressed for government support of R & D in industries where our technological lead seems to be declining. The international competitiveness of particular American industries will depend in the long run on the government's policies with respect to science and technology, but this does not mean that government support for science and technology should be focused on industries experiencing problems in meeting foreign competition. As pointed out in the next section of this paper, whether or not more R & D should be supported or encouraged in a particular industry depends on the extent of the social payoff from additional R & D there, not on whether or not our technological lead there seems to be declining.

8.9 Public Policies toward Civilian Technology

The federal government finances about half of the research and development in the United States. During the 1950s and 1960s, over 80 percent of the government's R & D expenditures went for military and space projects. During the 1970s, this percentage fell to about 63 percent. Federal expenditures on civilian R & D (notably health, energy, environment, transportation, and communication) have increased considerably as a percentage of the total, as shown in table 8.17. This is a noteworthy shift in the composition of federal R & D expenditures.

The rationale for government support of R & D varies from one area of support to another. National security and space exploration, for example, are public goods—goods where it is inefficient (and often impossible) to deny their benefits to a citizen who is unwilling to pay the price. For goods of this sort, since the government must take the primary responsibility for their production, it must also take primary responsibility for the promotion of technological change in relevant areas. Of course, such R & D results in a beneficial spillover to the civilian sector, but the benefits to civilian technology seem decidedly less than if the funds were spent directly on civilian technology.

Market failure of some kind is the rationale for large federally financed R & D expenditures in other areas. In energy, for example, it has been claimed that the social returns from energy R & D exceed the private returns due to the difficulties faced by firms in appropriating the social benefits from their R & D. Further, it has been argued that risk aversion on the part of firms may lead to an underinvestment (from society's point of view) in energy R & D. Also, the availability of energy is often linked to our national security.

As shown in table 8.17, some federally financed R & D is directed toward the general advance of science and technology. Expenditures of this sort seem justified because the private sector will almost certainly invest less than is socially optimal in many of the most fundamental types of research, because the results of such research are unpredictable and frequently of relatively little direct value to the firm supporting the research, although potentially of great value to society as a whole.

Besides its financing of R & D, the federal government influences and supports civilian technology in a variety of other ways. The patent laws, the tax laws, federal regulatory policies, the antitrust laws, and government policies toward education—all have an impact on the rate of technological change. And in the period since World War II, all have been the subject of considerable and widespread debate. At present, much of this debate has surfaced in connection with the Domestic Policy Review on Industrial Innovation, discussed below.

For a variety of reasons, a number of economists, such as Arrow (1962), Griliches (1972), Mansfield (1976), and Nelson, Peck, and Kalachek (1967), have suggested that there may be an underinvestment in civilian R & D in the United States. Because R & D is characterized by substantial external economies, riskiness, and indivisibilities, such a tendency might be expected in a competitive economy. However, on

Table 8.17 **Percentage Distribution of Federal R & D Obligations, by Function, 1969–78**

Function	1969	1972	1974	1976	1978
National Defense	53.5	53.9	51.3	49.1	48.7
Space	23.9	16.4	14.2	13.3	13.1
Health	7.2	9.6	12.0	11.0	11.2
Energy	2.1	2.3	3.5	7.5	11.8
Environment	2.0	3.2	4.0	4.5	3.4
Science and Technology Base	3.3	3.6	4.0	4.0	4.0
Transportation and Communications	2.9	3.7	4.0	3.3	2.9
Natural Resources	1.3	2.1	2.0	2.3	[a]
Food and Fiber	1.4	1.8	1.7	1.9	1.9
Other	2.5	3.4	3.3	3.1	3.0
Total	100.0	100.0	100.0	100.0	100.0

Source: National Science Foundation 1977; 1978; 1979b.
[a]Included with environment.

a priori grounds alone, one cannot demonstrate conclusively that this is true in the brand of mixed capitalism found at present in the United States. A number of empirical studies (some of which are cited in section 8.3) have been carried out to estimate the social rate of return from R & D. In general, the results indicate that the marginal social rate of return has been very high, which seems to suggest that some underinvestment may in fact exist. However, existing studies are rough and should be viewed with caution.

To illustrate, Mansfield et al. (1977b) estimated the social and private rates of return from the investments in seventeen industrial innovations, most of them run-of-the-mill advances in the state of the art. The median social rate of return was over 50 percent, while the median private rate of return was 25 percent. In five of these cases, the expected private rate of return was less than 15 percent (before taxes), which indicates that they were quite marginal from the point of view of the firm. Yet their average social rate of return was over 100 percent. This study was replicated by both Nathan Associates and Foster Associates, and the results of their studies are in accord with those given above.

The federal government has made a number of proposals and efforts to stimulate civilian technology. In 1963 the Department of Commerce proposed a Civilian Industrial Technology program to encourage and support additional R & D in industries that it regarded as lagging. It proposed that support be given in important industries, from the point of view of employment, foreign trade, and so forth, which have "limited or dispersed technological resources." Examples cited by the department included textiles, building and construction, machine tools and metal fabrication, lumber, foundries, and castings. The proposal met with little success on Capitol Hill. Industrial groups opposed the bill because they feared that government sponsorship of industrial R & D could upset existing competitive relationships.

In 1972, former President Nixon, in his special message to the Congress on science and technology, established three programs related to federal support of civilian R & D. One was an analytical program at the National Science Foundation to support studies of barriers to innovation and the effects of alternative federal policies on these barriers. This program (the R & D Assessment Program) has provided a substantial addition to fundamental knowledge in this area, and is now part of the Foundation's Division of Policy Research and Analysis. The other two programs, one at the National Science Foundation and one at the National Bureau of Standards, were to be experimental programs to determine effective ways of stimulating innovation. Both of the latter programs no longer exist in their original form, although elements of them remain.

In 1978 and 1979, the federal government carried out a Domestic Policy Review on Industrial Innovation. The Industry Advisory Subcommittee involved in this Review prepared draft reports on (1) federal procurement, (2) direct support of R & D, (3) environmental, health, and safety regulations, (4) industry structure, (5) economic and trade policy, (6) patents, and (7) information policy. These drafts were discussed and criticized by the Academic and Public Interest Subcommittees involved in the review. Further, the Labor Subcommittee presented a report, as did each of a large number of government agencies. The overall result was a large and far-flung effort to come up with policy recommendations.

One theme that ran through the Industry Subcommittee's reports was that many aspects of environmental, health, and safety regulations deter innovation. As pointed out in previous sections, there is a strong feeling that this is the case in a number of industries, although it is recognized that we lack very dependable or precise estimates of the effects of particular regulatory rules on the rate of innovation. However, the recommendations of the Industry Subcommittee with respect to regulatory changes were met with considerable hostility by the Labor and Public Interest Subcommittees.

Another theme found in some of the Industry Subcommittee's reports was that tax credits for R & D expenditures should be considered seriously. Although this mechanism to encourage civilian technology has the advantage that it would entail less direct government control than some of the other possible mechanisms, it would reward firms for doing R & D that they would have done anyway, it would not help firms that have no profits, and it would be likely to encourage the same kind of R & D that is already being done (rather than the more radical and risky work where the shortfall, if it exists, is likely to be greatest). A tax credit for increases in R & D would get around some of these difficulties, but the problem of defining R & D remains. As might be expected, the Treasury Department is particularly concerned about this definitional problem.

In October 1979, President Carter put forth a number of proposals, based on the Domestic Policy Review. He asked Congress to establish a consistent policy with respect to patents arising from government R & D, and advocated exclusive licenses for firms that would commercialize inventions of this sort. He asked the Justice Department to write guidelines indicating the conditions under which firms in the same industry can carry out joint research projects without running afoul of the antitrust laws. Also, to reduce regulatory uncertainties, he asked environmental, health, and safety agencies to formulate a five-year forecast of what rules they think will be adopted.

In addition, President Carter proposed a new unit at the National Technical Information Service to improve the transfer of technology from government laboratories to private industry, and he proposed that the National Science Foundation and several other agencies expand an existing program of grants to firms and universities that carry out collaborative research. He also asked that a program to support innovative small businesses (currently under way at the National Science Foundation) be expanded by $10 million in 1981. And he proposed that government procurement policies put more stress on performance standards rather than specific design specifications.[4]

Although this program may have many beneficial effects, it is hard to believe that it can have a very major impact on the nation's technological position. As its principal architects are the first to admit, it is only a first step. This exercise, like its predecessors in previous administrations, demonstrates that it is not easy to formulate an effective, equitable, and politically acceptable program. Further attempts will almost certainly be made. In formulating future proposals, it seems to be generally agreed that any program should be neither large-scale nor organized on a crash basis, that it should not be focused on helping beleaguered industries, that it should not get the government involved in the latter stages of development work, that a proper coupling should be maintained between technology and the market, and that the advantages of pluralism and decentralized decision-making should be recognized (Mansfield 1976).

Finally, the emergence of technology assessment during the 1960s should be noted. As public awareness of environmental problems grew, more and more emphasis was placed on the costs (such as air and water pollution) associated with technological change in the civilian economy. Policy makers became increasingly interested in technology assessment, which is the process whereby an attempt is made to appraise the technical, political, economic, and social effects of new technologies. In 1972, Congress created the Office of Technology Assessment to help it anticipate, and plan for, the consequences of the uses of new technology. Unfortunately, it is notoriously difficult to forecast the future development and impact of a new technology, and technology assessment has proved very hard to carry out.

Also, the effects of the energy crisis on United States technology policy should be cited. Between 1974 and 1977, federal R & D obligations for energy development and conversion increased at an annual rate of over 50 percent. Between 1977 and 1978, they increased at an annual rate of over 20 percent. Many aspects of the government's R & D policies in the energy area have been controversial. In 1979 one of the biggest issues was whether the government should grant massive subsidies to fund the commercialization of synthetic fuels. As Pindyck (1979), Stobaugh and Yergen (1979), and others have pointed out, there are very considerable problems with some of these proposals. In November 1979, the Senate approved a $19 billion program to develop a synthetic fuels industry.

8.10 Summary and Conclusions

During the thirty-five years that have elapsed since World War II, at least eight very important changes have taken place in American productivity and technology. First, the rate of productivity increase, which was relatively high up until about 1966, fell somewhat during 1966–73 and then took a nosedive in the mid-1970s. Some of this decline can be attributed to changes in the composition of the labor force, reductions in the rate of growth of the capital-labor ratio, and increasingly stringent pollution, safety, and health regulations. But most of the decline during the mid-1970s cannot be explained in this way. To some extent, it may have been due to the disruptions caused by the quadrupling of oil prices and the double-digit inflation of the mid-1970s. To some extent, it may have been due to a slowdown in the rate of innovation. The unfortunate truth is that we do not know how much of the decline is due to each of these factors.

Second, R & D expenditures in the United States increased at a relatively rapid rate until the middle 1960s, after which they remained relatively constant in real terms. After 1967, federal R & D expenditures decreased, due in large part to reductions of space and defense programs, while industry's R & D expenditures increased, but at a much slower rate than before 1967. As a percentage of gross national product, R & D expenditures fell from 3.0 percent in 1964 to 2.2 percent in 1978. Also, there was a substantial decline between 1967 and 1977 in the proportion of company financed R & D expenditures devoted to basic and relatively risky projects. These developments are important because a variety of econometric studies indicate that an industry's or firm's rate of productivity increase is related significantly to the amount it spends on R & D. Also, holding constant the amount spent on R & D, an industry's rate of productivity increase during 1948–66 seemed to be directly related to the extent to which its R & D was long term.

Third, the employment of scientists and engineers grew relatively rapidly from 1950 to 1963, less rapidly from 1963 to 1970, and very slowly from 1970 to 1974. In many major firms, the engineering labor force is much older than in 1960. The percentage of bachelor's (and first professional) degrees awarded in engineering and in the physical and environmental sciences decreased considerably between 1960 and 1975.

Fourth, when patents are classified by date of application, the peak patenting rate for United States residents occurred in 1969, after which it declined. In practically all of the fifty-two product fields for which data are available, the patent rate declined during the 1970s. The only exceptions are in drugs, agricultural chemicals, and motorcycles, bicycles, and parts. Counts of innovations seem to indicate that in some industries, notably pharmaceuticals, the rate of innovation declined during the 1970s. Also, there is some evidence that the percentage of United States innovations that are radical breakthroughs tended to decrease during the 1960s and 1970s.

Fifth, when other factors are held equal, the available evidence indicates that there may have been an increase in the rate of diffusion of innovations. New processes tend to spread more rapidly from firm to firm and to replace old processes more quickly than in the past. Also, there is some evidence that new products are imitated more quickly than in the past. In part, this has probably been due to the growth of more extensive and effective mechanisms to transmit and evaluate technical information.

Sixth, the longstanding technological lead that the United States has maintained in many branches of manufacturing technology seems to be lessening, and in some areas it may no longer exist. Productivity has been increasing less rapidly in the United States than in other major countries since 1960. Rough data seem to indicate a decrease in the proportion of major innovations originating in the United States. Although it is very difficult to make meaningful international comparisons of technology levels, there seems to be widespread concern among policy makers on this score.

Seventh, the rate of international diffusion of technology has tended to increase, due in part to the growth of multinational firms. United States-based firms seemed to transfer newer technology to their overseas subsidiaries more in 1969–78 than in 1960–68. The percentage of R & D carried out overseas has increased considerably, and some major firms organize and integrate their R & D on a worldwide basis. According to a study of thirty major firms, about 30 percent of the returns from these firms' 1974 R & D were expected to come from foreign sales or foreign utilization. And in the bulk of the cases, foreign subsidiaries were expected to be the principal channel of international technology transfer in the first five years after commercialization. Although some groups have pressed for measures to regulate the international transfer of technology, most economists seem to be skeptical of such proposals.

Eighth, the federal government, which supports about half of the R & D in the United States, has reduced the proportion of its R & D going for defense and space, and increased the proportion going for civilian purposes (notably health, energy, environment, transportation, and communication). There is some evidence that there may be an underinvestment in civilian R & D, and that government regulations and policies may have erected unnecessary obstacles to innovation. A series of examinations of United States technology policy has taken place.

Unfortunately, although it is becoming clearer that a variety of problems exists in this area, it is less obvious how much the government can or will do to help solve them. To a considerable extent, this reflects the fact that we know less than is frequently acknowledged concerning the efficacy (and costs) of various policy alternatives that have been proposed.

Finally, it is important to recognize that America's technology policies cannot be separated from its economic policies. Policies which encourage economic growth, saving and investment, and price stability are likely to benefit our technological position. Just as many of our current technological problems can be traced to sources outside engineering and science, so these problems can be ameliorated by policies relating primarily to nontechnological areas. Indeed, the general economic climate in the United States may have more impact on the state of United States technology than many of the specific measures that have been proposed to stimulate technological change.

Notes

1. National Science Foundation, *Methodology of Statistics on Research and Development* (Washington, D.C.: Government Printing Office, 1959), p. 124.
2. When the annual rate of productivity change during 1948–76 is used instead, this relationship no longer exists, but this may be due to the changes over time in the extent to which various industries' R & D have been long term. More work is needed on this point.
3. See A. Biemiller's testimony on 28 July 1971 in *Science, Technology, and the Economy*, Hearings before the U.S. House Subcommittee on Science, Research, and Development (Washington, D.C.: Government Printing Office, 1972), p. 53.
4. Other proposals were made as well. For a more complete account, see *The President's Industrial Innovation Initiatives*, Office of the White House Press Secretary, 31 October 1979.

2. *Ruben F. Mettler*

Technology: A Powerful Agent for Change

Introduction

An invitation to say a few words about technological changes and their effect on the postwar domestic American economy is certainly a challenge. The subject is rich in opportunity for speculation—and rich in opportunity for error.

Ruben F. Mettler is chairman and chief executive officer of TRW, Inc.

Technological change during the postwar period has been rampant. One need not search far to see powerful and pervasive technological innovations introduced into the economy in recent years, based on fundamental advances in mathematics, physics, chemistry, geology, and biology, and their applications in fields of direct significance to the economy: agriculture and food production; medicine and human health; energy conversion and utilization; transportation; construction and urban development; communications and information processing; instrumentation and control; industrial production; extraction and conversion of raw materials; military development and national security; and earth and space exploration.

Some of the major technological changes have been slow and evolutionary and some have been sudden and dramatic. New scientific and engineering understanding and brilliant inventions only become innovations that significantly influence the economy with the addition of management, capital, marketing, distribution, production, maintenance, and widespread extensions of human skills.

Changes in the American and in the world economy, while heavily influenced by technological change are, of course, more deeply rooted in the world's major political, social, and economic forces, and must be judged and interpreted in the context of:

1. Population growth and the related need for food and shelter and education and jobs, with the resulting pressures on political and social and economic institutions
2. Limitations on the supply and distribution of energy and national resources as well as on related environmental issues
3. Enormous variations in income levels per capita in different parts of the world
4. Dependence on international trade and investment and continuing real economic growth
5. Reconciliation of conflicting cultures and value systems as modern communication and transportation increasingly force them into intimate contact
6. Vulnerability of vital and increasingly complex national and international institutions to disruption by small groups
7. Foreign policy and national security issues related to these major problems in a world possessing nuclear weapons

Rather than discuss technological changes in general terms, I wish to comment on three important changes in our domestic economy which have been heavily influenced by technology during the past thirty years and which are likely to be equally or more important during the next thirty years. In addition, I will comment on a sweeping technological wave of such significance to economic development that it requires special treatment.

I won't comment directly on Edwin Mansfield's excellent background paper on technology and productivity, except to underscore and emphasize his very last paragraph in which he cites the high leverage which sound general policies encouraging economic growth, savings, investment, and price stability have on stimulating technological progress.

International Constraints on Our Domestic Economy

Few changes in the domestic American economy in the postwar period appear to me to be as significant and as inadequately recognized, particularly by national policy makers, as those changes—heavily influenced by technology—which increasingly bind the domestic economy to the rest of the world, and make it a more dependent subelement of a larger and more powerful economic system.

These binding forces exert a discipline on national policy makers by creating significant conflicts between politics and policies which are popular domestically but incompatible with international reality. They force on business executives the recognition that many of their markets are worldwide in scope and that they must compete worldwide to survive in those markets. Some of the puzzles and surprises in postwar domestic economic analysis and modeling may be the result of a preoccupation with internal variables and insufficient recognition of the scope and significance of external international forces on our domestic economy. All of these effects are amplified by our voracious appetite for energy.

Multinational corporations (American and foreign) have been the principal agents for the large increase in international trade in the postwar period and for the dramatic postwar expansion in international investment, credit, and money that now link our domestic economy ever more tightly to the rest of the world.

These linkages and the resulting constraints on our domestic economy have in large part been fashioned by technological changes which are still gaining momentum and may be even more important in the years ahead. Included among the more important technologies working to bind our domestic economy to the rest of the world are those related to agriculture and food production and to finding, producing, transporting, and refining massive quantities of petroleum products. But I'd like to comment today especially on (1) communications and information processing and (2) jet transportation.

In worldwide communications a sudden qualitative change took place in the 1960s when high capacity commercial communication satellites were first launched into orbit. The first such satellite placed in synchronous orbit over the Atlantic provided more communications capacity than all of the transatlantic cables and radio links previously built, at a small fraction of the per-channel cost. In just a few years, satellites equipped with wide-band transmission links came to dominate long distance communication of voice, data, and television to all parts of the globe, at significantly reduced costs.

In parallel with this quick expansion of worldwide communications capacity came the development and volume production of digital computers and related information processing systems, and the rapid development and expansion of the worldwide system of jet transportation.

Communications and computers, backed up by quick and convenient passenger transportation, have been and are essential tools in the international expansion and control of multinational industrial and banking institutions, with their significant effect on the world economy and hence on our domestic economy.

Dramatic Changes in Military Technology

During the postwar period there have been a number of concurrent technological breakthroughs that have dramatically altered the nature and power of military forces. These changes have had a first-order effect not only on the foreign policy of the United States and of its adversaries and allies, but also on the world economy and hence also on our domestic economy. The effects of these changes are now gathering momentum and will be even more significant in the next thirty years.

During the 1950s the almost concurrent development of small nuclear warheads (with unbelievably greater destructive power than even the atomic warheads of the 1940s, which in turn had overshadowed all prior explosives) and large rocket-propelled missiles of intercontinental range, permanently changed the nature and power of strategic military forces. For the first time in history, strategic military forces with the power to completely destroy an industrialized society became an instrument of foreign policy.

During the 1960s and 1970s further development of sensing instruments and control electronics gave these missiles pinpoint accuracy. High accuracy combined with large numbers of missiles and warheads make it possible for an aggressive superpower to aspire to having a first-strike capability able to deliver a knock-out blow, again drastically altering the strategic military equation.

From a position of overwhelming strategic military dominance during the 1950s and early 1960s, the United States followed policies which (it is now widely, though belatedly, recognized) will result in strategic military superiority passing to the Soviet Union during the 1980s, unless vigorous new United States military (nuclear and nonnuclear) development and production programs are initiated and sustained during the next decade. During 1970–78, the Soviet Union spent about $100 billion more (conservatively estimated) on military equipment and facilities and about $40 billion more on military R & D than did the United States. In the crucial category of strategic weapons and R & D, they outspent the United States by more than two to one.

I believe these changes, although difficult to quantify, have already had important effects on our domestic economy in the past several decades and will be even more significant during the next several, particularly when viewed in the context of the increasing vulnerability of our economy to interruption of supplies and our increasing linkage to the world economy and world political forces. If allowed to proceed unchecked, the Soviet Union, under an umbrella of strategic nuclear superiority, could be more aggressive and adventuresome in using conventional military forces and in exerting diplomatic pressure.

Consider first some effects internal to our domestic economy. Even though our military programs have been significantly less aggressive than those of the Soviet Union, they have absorbed federally funded R & D and a significant fraction of industrial technological talent during the 1960s and 1970s, with a resulting penalty to new commercial processes and products and to industrial productivity. As we look to the 1980s, it is now increasingly evident that the United States must step up its military programs or live with Soviet military dominance with all of its unacceptable consequences. In this situation, the negative effects on our domestic economy of large military expenditures will continue and may increase. The Soviet Union, with a smaller and less productive economy than ours and with much larger military programs may also suffer a penalty to domestic productivity and economic strength.

Two of our economic competitors, Germany and Japan, have gained in productivity and relative economic strength in recent decades by holding their military expenditures to a very low level and depending on the United States for strategic military security. Essentially all of their research and development and industrial capacity has been focused on their civilian economy. How significant has this effect been? And what military policies will (or should) they follow during the rest of this century to share in a common defense?

Thinking more broadly, how much of the weakness of the dollar (and the high price of gold) in recent years stems from loss of confidence in the American military capability? What would be the effect on our trading partners, particularly our energy suppliers, if we failed to maintain our position in nuclear and nonnuclear forces? Reasonable political stability is essential to international trade, investment, credit, and economic growth. Hence, should not our foreign policy be more explicitly focused on these matters? Can we get through the next decade without military intervention in the Middle East? How do we cope with almost certain nuclear proliferation to smaller countries, both friendly and unfriendly to the United States?

I have no answer to these questions, but include them because I believe they are too often omitted in considering economic issues and must certainly be included in a discussion of technological development in relation to our domestic economy. There is no reason to believe that technological changes in the military field will stop or slow down. On the contrary, they are more likely to accelerate.

The Next Energy Transition

Few issues have been and will be more important to our domestic economy and to the stability of the world economy than those related to energy supply, utilization, and pricing. During the past thirty years we have gone through an energy transition and during the next thirty years we will go through another.

So much has been written and said (both sense and nonsense) about energy in recent years that one is tempted just to skip it. Yet no serious discussion of technological change and our domestic economy can properly omit energy.

Highly effective technology directly applicable to our major energy issues (both those related to conservation and supply) has been developed during the postwar period. We have the scientific and engineering foundation for significant and much needed improvements in our energy-related technology during the next several decades. Although necessary to a successful energy transition, technology per se is not the real issue. Petroleum-related technology has flourished during the postwar period, but the most startling development is the extent to which our nation has failed to use other available and applicable technology in addressing our major energy needs for conservation and supply and early development of new energy-efficient products. This situation developed in part because economic incentives for its use have been minimal, and disincentives to its use have been actively promoted; and in part because of largely exaggerated fear of unwanted side effects. The failure to permit the price mechanism to function has been particularly noteworthy.

The major energy issue is whether our political, social, and economic institutions (and those of other nations) have the strength and flexibility to adapt to the institutional changes needed, especially those needed to achieve a reasonable definition of the common purpose and the means to work effectively toward achieving it. As the leading industrial nation in the world, one would expect leadership from the United States in this effort.

If man can be defined as "a tool-making animal with foresight" then we have surely failed the test. Even if we make the essential high priority effort to conserve energy and reduce its use per unit of output, energy supply will continue to be central to the growth and efficiency of all industrial economies. For the past ten years, making progress on our energy problems and those of other nations has been regarded as vital to controlling inflation, vital to our national security, essential to economic growth and increased productivity, necessary for protecting our environment, and the only way to achieve a productive and stable foreign policy. If those reasons aren't motivation enough, a few more reasons to pull ourselves together could easily be added.

In the energy field, technological change has been slower than needed, to the detriment of our domestic economy. Future economic growth and improvement in our productivity will depend heavily on stimulating wider and more rapid use of advanced technology in energy.

A Second Industrial Revolution

Developing like a storm during the 1950s, the 1960s, and the 1970s, and now ready to burst forth during the next thirty years is "a second industrial revolution." Its full dimensions are still unclear, but there is no doubt that its scope and power, already highly significant both to our domestic economy and to the world economy, will grow enormously in the years ahead.

The first industrial revolution was heavily based on mechanical engineering in providing tools, machinery, and new sources of power to replace human labor. The second, now developing, is based on a number of concurrent technological changes in the fields of communications and information processing.

Much has been said about the dramatic changes in these fields, but their effects may still be understated. Impressive advances have been taking place simultaneously in a wide range of interrelated technologies, which put together multiply their potential effects on economic development. These interrelated technologies include, listing just a few: transistors, integrated circuits, LSI, microprocessors, VLSI; compact and readily accessible data storage of massive capacity; computers, large and small; digital communication switching and signal processing; advanced programming languages and highly sophisticated programs; satellites as communication stations; audio-visual sensing and displays; word processing and voice coding; optical communication; highly intelligent terminals; and electronic printing. Parallel advances in all of these related aspects of communications and information processing have created an explosion of possible applications.

The 1960s and early 1970s were characterized by a buildup of very large central computing capacity; the late 1970s and 1980s have been and will be characterized by widespread distribution of computing power via communication links to a large number of remote locations, spread through all parts of the economy. Driven by dramatic improvements in performance and very large reductions in costs, there has been an almost explosive demand for more communication and information processing in industrial, financial, government, professional, and educational institutions. (As an example of the dramatic cost reduction, a small computer using a few microprocessors and selling today for about one hundred dollars can outperform a large computer selling for over one million dollars fifteen years ago. Roughly similar cost reductions have occurred in related equipment and systems. By way of perspective, if a corresponding reduction had been made in the price of a Cadillac, you could buy one today for a few dollars.)

In addition to creating new markets and a wealth of new products which have given a boost to economic growth, this new field has made significant contributions to improved productivity. It will be important to our international competitive posture, and a continuing large investment will be needed to maintain our current leadership in these new technologies.

In one sense, synthetic electronic intelligence is being produced and used to extend man's brain—if you like labels, consider "intellectronics." One of the particularly interesting effects of this technology on our economy arises from its potential for both positive and negative effects on how institutions of various types are managed. You heard some comments earlier on some of the negative effects as related to government intervention in our economy. On the positive side, there is a large potential for improving the productivity and profitability of business institutions by effectively using communications and information processing technology. Most studies of productivity underestimate, in my view, the differences in productivity attributable to management skill.

Conclusion

In the context of worldwide political, social, and economic issues, technological change has had a major impact on the domestic American economy during the postwar period and will continue to have a major impact during the next thirty years.

Sound political and economic policies which encourage economic growth, savings, investment, and price stability have high leverage in stimulating technological progress and focusing it on improving productivity and on new markets, products, and related new job opportunities.

Among the most significant changes in the postwar American economy are those which increasingly bind our domestic economy to the rest of the world and make it a more dependent subelement of the larger and more powerful world economic system. This trend has been heavily influenced by technological change. It is given added significance by dramatic changes in military technology and in the relative military strength of the United States and the Soviet Union during the postwar period. It is vital to our national security and our economy that we initiate and sustain vigorous new military (nuclear and nonnuclear) development and production programs during the next decade. The dangers arising from our failure to maintain a proper military posture relative to the Soviet Union have been amplified by our failure to use market incentives to stimulate the use of available technology in addressing our energy needs.

Phenomenal concurrent advances in a wide range of new technologies in the fields of communications and information processing are leading us into "a second industrial revolution" of major importance both to our domestic economy and to the world economy. These changes will reshape some major industries and have significant effects on productivity, on international competitive patterns, and on how both government and business enterprises are managed. Technological change and its effect on our economy should not be expected to slow down. On the contrary, it is more likely to accelerate. Effective use of our scientific and technological resources will be an important, and possibly a crucial, economic issue for the period ahead.

3. *David Packard*

Productivity and Technical Change

In the two decades that reached from the mid-1940s to the mid-1960s, the United States had a healthy economy, characterized by rapid economic growth and low inflation, and propelled by great technical progress. This technical progress helped general annual increases in productivity in excess of 3 percent and was a major contributor to the overall well-being of the economy.

The economies of Europe and Japan recovered from the destruction of World War II during this period, and by 1965 were growing and achieving annual productivity increases even larger than those in the United States; in the case of Japan alone, productivity was increasing at annual rates of from 6 to 8 percent.

Since about 1970, the rates of improvement in productivity have declined in the major industrial countries of the world, with corresponding declines in the health of their economies from the robust decades following the war. This serious deterioration in the well-being of the free world economy has been of great concern to businessmen, economists, and people in government at many levels. It is difficult to find much to be said that has not already been said about the subject. Yet the problem

David Packard is chairman of the board of the Hewlett-Packard Company.

is so important that it is imperative that the search for answers continue and that action which will improve the situation be identified and undertaken. It seems to be generally agreed among economic scholars, managers, and government executives that improvement in productivity would be helpful in reducing inflation and promoting economic growth.

The productivity of a business enterprise is determined by a number of factors, but the prime influences are management and the application of technological innovation.

Management plays a major role in determining the structure of the organization, influences the quality of supervision, provides training for the workers, and works to motivate employees. There can be significant improvement in productivity from management-directed activity, as shown by the range of productivity that can be measured between well-managed and poorly managed enterprises.

While productivity gains can be made by management leadership that encourages people to work harder and work smarter, technology is the base of most major gains in productivity. The use of better tools, better equipment, and better manufacturing processes is the only way productivity can be improved once management's contribution has been optimized. Even with the handicap of poor management practices, better tools, equipment, and processes will usually improve productivity.

It is not often that one finds a manufacturing facility completely equipped with the latest and most productive tools, machinery, and processes. In the first place, these expensive items are seldom replaced as rapidly as better equipment becomes available. Depreciation policies and inadequate capital generation often limit replacement. Sometimes management strategy does not give the highest priority to productivity improvement, perhaps because the incentives are not right.

Industrial productivity has been higher in Europe and Japan since the war, in part, at least, because new plants employing the most modern equipment were built to replace those destroyed during the war while plants in the United States continued to operate with older, less productive equipment. Also, many of the industries in these countries were playing a catch-up game.

Inflation, coupled with the government's traditional fiscal and tax policies, have made the replacement of older equipment more and more expensive and difficult, although the investment tax credit allowance is a step forward. It is one of the few incentives left to industry to improve productivity through new equipment. A more liberal depreciation policy would also help in the more rapid replacement of older equipment, although to be effective, management would have to place less emphasis on short-term profits.

Nearly every enterprise could improve its productivity by the more extensive use of the newer and more productive equipment that is already available, but the greatest contribution clearly must come from the acceleration of the discovery and the innovative application of new technology. Technology is an important contributor to productivity in areas beyond development of better, more effective equipment and processes. Technology makes its most dramatic contribution to productivity in the creation of entirely new products from which new business enterprises and entirely new industries develop.

The United States has had an outstanding record in being at the forefront of new industry creation throughout the entire twentieth century. Automobiles, aircraft, plastics and chemicals, electronics, communications, and computers are just a few examples of that leadership. Whether the productivity gains that result from new industries based on new technology are properly reflected in the indices we use to measure productivity or not, each of these industries has given us a quantum jump in productivity, however you choose to define it.

The creation of a new industry based on technology requires the innovative application of scientific knowledge to do something that is useful and that needs to be done. The process can involve innovative application of old technology, but the most dramatic examples come from the discovery of new technology. A recent example is the invention of the transistor and related solid-state electronics technology, followed by the development of large-scale integrated circuits.

This new technology has made possible the modern computer industry. Thousands of new products and new business enterprises have been generated in this multi-billion-dollar industry in which again the United States was, and still is, in the lead. Computers have made a considerable contribution to increased productivity throughout industry, although there may be some debate about just how much. The industry itself has achieved productivity gains estimated at 35 percent per year reflected in lower prices and increased performance.

Two ingredients are necessary to make these quantum gains. One is the discovery of new scientific knowledge. The other is the creation of the proper environment, the incentives, and the resources to encourage the innovative application of the new technology to something useful that needs to be done. Both ingredients are necessary to support a productive research and development endeavor.

We often discuss research and development without considering that a very wide range of activities is involved. Research is generally considered to be the search for new knowledge, but more often it involves gaining a better understanding of what is already generally known. Development generally means practical application of scientific knowledge to produce new tools, new processes, and new products. Here, sometimes, research in terms of a search for new knowledge is also needed, and thus no clear line can be drawn between research and development, and indeed they are often linked together.

The worldwide bank of basic scientific knowledge is generally available to scientists and engineers of all nations through widespread publication. Good basic research work is done in the United States, nearly every European country, Japan, and the USSR.

There are some restrictions on the availability of scientific knowledge because of national security considerations, and there is some private control of scientific knowledge, but neither is a serious impediment to the general availability of new scientific knowledge. There is sometimes an advantage to early, and presumably exclusive, access to new knowledge, but is seldom lasts for long.

There has been considerable discussion recently about whether the United States is falling behind in research and development (R & D), but the discussion does not always make a distinction between the discovery of new basic knowledge and the whole host of other activities that goes on under the heading of R & D.

The number of patents issued is often used as an index of the level of R & D, but only a few patents involve new basic knowledge. Most patents involve the use of existing technologies. The number of patents issued may be a general indication of the country's scientific and engineering activity, but this is not a good indication of the level or quality of basic research.

We have by no means used up our basic scientific knowledge. However, common sense tells us we should try to add to scientific knowledge at the same time we utilize what we have. It is never possible to predict a scientific breakthrough to a new field of knowledge. Many times in the past, knowledgeable people have proclaimed that science has already discovered everything that can be discovered, but these forecasters of the future of science have always been proven wrong. New scientific knowledge will bring about the creation of new products and entirely new industries in the future as it has in the past. Furthermore, the payoff will be great, for new scientific knowledge is the cornerstone of technical change. It will continue to contribute to productivity in the future, as it has in the past.

The United States should consider new and more effective ways to increase the level of R & D in domestic industry with particular emphasis on how to encourage a higher level of basic research by industry. We should also look for ways to improve effectiveness of established and continuing federally supported R & D.

One suggestion to encourage an increase in the level of R & D by industry is to allow a federal tax credit for R & D. There is no doubt that the establishment of such a tax credit would encourage management to increase the level of funding and activity. However, unless this credit were established only for increases in R & D above previous levels, we would find that the credit would be used to pay for a great deal of work that would have been done anyway.

Since a substantial part of the cost of R & D is in the instrumentation and equipment required, the investment credit might be increased by an additional percentage, say 10 to 20 percent of cost for machinery and equipment used in R & D. Faster write-off of equipment and facilities used for R & D would also help. There would be some definition problems here, as there would be for tax credits for total or incremental R & D expenditures, but I believe they would be manageable.

Total federal support for R & D is very large, but much of it is for space and defense programs, health, and more recently, energy. These expenditures have had only marginal effect on improving the productivity of the economy.

High-energy physics receives very large federal support, and so far has had very little payout in the areas of productivity, although there has been some. Most solid-state electronics R & D is now funded by private sources, and here the payout in productivity has been tremendous. It will continue to be large in the future. Increased federal funding could be useful in this area, and, in fact, the Department of Defense has plans to put more money into large-scale integrated circuit R & D.

I believe the entire Department of Energy program of support for R & D should be reexamined to make sure all promising areas of basic research are adequately funded. Here the program should be patterned after the brilliant Office of Naval Research (ONR) program established in 1946. This ONR program deserves a great deal of credit for keeping the United States ahead of the world in many areas of technology. Federal support, through the ONR, made it possible for Stanford University to create an outstanding program in electronics in the two decades after the war. Important research work was done in high-frequency vacuum tubes called traveling wave tubes and backward wave oscillators. Later, major contributions to the field of solid-state electronics technology were made at the Stanford laboratories. An outstanding faculty was assembled and fine students were educated. Much of this research and many of the students contributed to the impressive growth of new electronics companies on the San Francisco Peninsula. Stanford could not have made these important contributions in electronics research and education without the funding provided by ONR. The "Silicon Valley" could not have happened without this federal support of Stanford University.

Federal funding of R & D should emphasize basic research, since it has been shown that adequate funding of basic research in all promising areas of technology will have a high payoff over the long run. Development, on the other hand, will be done better by the private business sector.

The imaginative application of scientific knowledge to create new products, new business enterprises, and new industries is called innovation. The economic and social climate of the United States has fostered innovation from the early days of the Republic. Yankee ingenuity it was called in the nineteenth century. The combination of pioneering attitudes, unlimited risk capital, incentives to innovate, and new technical knowledge have always made up the magic formula for the development of new products and the building of new industries, as well as productivity improvement in the old.

Serious questions are being raised as to whether pioneering attitudes are disappearing in the United States: societal attitudes that advocate no growth, claim big is bad, and express increasing dissatisfaction with the material side of life, probably combine to foster the idea that increasing productivity should not have a high priority on the list of human endeavors. The availability of risk capital has been reduced by federal tax policy, and other government policies have reduced incentives and established formidable hurdles in the path of technical innovation.

The changes in federal tax policy in 1970, which increased the capital-gains tax, effectively dried up sources of risk capital for the establishment of new technical enterprises in the United States.

A Small Business Administration study showed that new capital acquired by small firms through public offerings of equity dropped from a level of 548 offerings in 1969, which raised nearly $1.5 billion, to 4 offerings in 1975, which raised $16 million. Fortunately, the capital-gains tax rate was reduced last year, and venture capital is again becoming available for new and small business enterprises, where a great deal of innovation takes place.

During the late 1950s and early 1960s, when a great many new electronics companies were established, the availability of stock options caused many scientists and engineers to leave older established firms and cast their lots with newly formed firms. If the firm became successful, the rewards were great, for when the stock option was exercised, the stock had considerable value. The gain was not taxed until the stock was sold. The recipient could either hold the stock in the hope of further gain or sell it and pay the tax from time to time as funds were needed. This was important because innovative technical people almost always had more freedom to use their expertise and ingenuity in a small firm, especially when they had the great incentive of ownership participation. This may account for the fact that in many industries small and medium-sized firms have often been more innovative.

Congress, in an action to prevent what it thought was a tax loophole, made stock options taxable when exercised, and the recipient usually had to sell the stock to pay the tax. To compound the problem, an SEC regulation prevented the person from selling the stock for a considerable time after it was received if the person involved had a management role. In effect, stock options as incentives for technical people to follow their pioneering spirit were largely eliminated. There is now an effort to restore the stock-option incentive, and to do so would restore an important stimulus for technical people to undertake risky, but potentially profitable ventures in newly established enterprises.

Productivity in older and larger established firms is influenced by technical change in a somewhat different way. Such firms use many engineers and scientists in developing new products, devising new production methods, and designing better production equipment and tooling. The ability of engineers and scientists doing this kind of work to improve productivity has been seriously affected by the unprecedented growth of governmental regulations since 1970. In many cases, technical people have been required to spend much of their time dealing with regulatory problems instead of doing the kind of engineering and scientific work that would otherwise contribute to productivity improvement.

Governmental regulations, in fact, may be the largest and most important factor in the decline of productivity in the United States. Regulations have been a serious problem in every aspect of industrial expansion. The nuclear power industry may represent the worst of this situation.

It should require from four to five years to design, build, and bring on line a new power plant, but regulatory procedures have extended the time required threefold. It now takes from twelve to fifteen years to bring a new plant on line. We may reach the point where it will be impossible to build a nuclear plant or any other major facility in the United States because of excessive regulation.

Regulatory procedures are causing costly delays in even the most noncontroversial projects. I am involved in building an aquarium on the shore of Monterey Bay. Although everyone thinks it is a great idea, it is taking a full year to get approvals from all of the agencies involved. Ten years ago, only a month or so would have been required. It is impossible to keep architects and engineers working productively in this kind of a situation.

Regulations have seriously reduced the productivity of new-product development in every industry. The introduction of new drugs has become much more expensive and time consuming, and even in the development of electronic instruments, which have few health and safety problems, the regulatory agencies involved have increased development time and cost.

The impact of government regulation on small or newly forming enterprises is even more serious. The Occupational Safety and Health Administration code book contains some twenty-eight thousand regulations, and OSHA is only one of many, many regulatory agencies. It is utterly impossible for an individual entrepreneur starting a new business to know, understand, and deal with all of these regulatory matters and still have any time or energy left to deal with the mainstream work of his enterprise. It is not surprising that fewer new technically oriented firms are being started today. What is surprising is that there are any.

We need to find a way to apply more commonsense judgment to matters of regulation so that we can continue to preserve and protect all the important things in our society . . . things like the environment, individual dignity, and the freedom to innovate and produce.

From my experience, I have concluded that there is a significant decline in productivity because of the changes in societal attitudes I have already alluded to and also changes in managerial attitudes and policies. Specifically, if management people were to develop a better appreciation of the influence of technology on productivity, basic research would receive more support in the private sector. If management people were to put more emphasis on long-term performance instead of quarter-to-quarter or even year-to-year results, better decisions that affect productivity would be made.

In conclusion, there are a number of things the federal government can do to improve the productivity of our economy. The government can and should give a higher priority to increasing productivity in every action that is taken which has a significant impact on the economy. This applies to tax policy, regulatory policy, and policies that affect federal support of R & D.

I believe the private sector can and should do a better job as well. I believe productivity would improve if managers were to place more emphasis on long-term performance, as I mentioned earlier.

If both the federal government and the private business sector were to give productivity a higher priority among all of their other concerns, this would also influence the attitude of the general public. It would help bring about a general realization that there can be no improvement in the economic well-being of the average individual without an improvement in the overall productivity of our economy.

I am convinced that, to the extent the importance of productivity improvement to the welfare of the individual is understood and accepted, a better climate for productivity will be established.

Summary of Discussion

A lively debate centered on the appropriate role of the federal government in the area of research and development (R & D). Milton Friedman saw an inconsistent attitude of businessmen in their views about the government's role in R & D. On the one hand, they complain that government regulation stifles R & D while on the other they ask for special government favors for R & D, such as tax credits. Friedman saw no reason why a tax credit on R & D matched by tax increases elsewhere should be any more effective in raising productivity than an end to special tax incentives and a general reduction of tax rates. Friedman disputed the notion that a government role was appropriate for research projects with long lead times. It is the market, and not the government, he declared, which has the longer time horizon.

Arthur Okun held that the free market fails to reward adequately the production of knowledge and therefore generates too low a level of R & D. Government subsidization of R & D (starting with patent laws and grants for basic research) is an economically efficient response. Friedman agreed that the free market is likely to be imperfect in generating R & D but suggested that so too is a system with a large government role. It's a choice of two evils, he declared. Okun responded that it would be remarkable if the "best" system were either all governmental or all private; some mix is inevitable.

Feldstein took issue with Friedman on targeted versus general tax cuts for R & D: a general tax cut might stimulate R & D, but an equal tax cut targeted on R & D should provide a larger stimulus. Friedman answered by observing that the goal is not the stimulation of R & D but of productivity growth. And for the latter goal, he argued, the tax issue is unclear.

Edwin Mansfield shed some more light on the question of tax policy. He noted that a good definition of "research" for tax incentive purposes is very difficult to devise. Moreover, where other countries have attempted to create tax incentives for R & D, the results, according to the little evidence that is available, appear to have been small. He stressed that very little is known about the effects of such programs and that there is a need for much more economic research in this area.

Mettler and Packard cited a number of government-supported programs of basic research that have had significant beneficial effects on technological development. Packard reiterated the favorable experience of the Office of Naval Research.

References

Arrow, Kenneth. 1962. Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity*, National Bureau of Economic Research. Princeton: Princeton University Press.

Baranson, Jack. 1976. Technology transfer: Effects on U.S. competitiveness and employment. Report prepared for the U.S. Department of Labor. Washington, D.C.

Beardsley, George, and Mansfield, Edwin. 1978. A note on the accuracy of industrial forecasts of the profitability of new products and processes. *Journal of Business* (January).

Blackman, A. W. 1971. The rate of innovation in the commercial aircraft jet engine market. *Technological Forecasting and Social Change*, nos. 3–4.

Brach, Peter, and Mansfield, Edwin. 1979. Engineering employment by American manufacturing firms. Philadelphia: University of Pennsylvania.

Cain, G., Freeman, R., and Hansen, W. L. 1973. *Labor market analysis of engineers and scientists.* Baltimore: Johns Hopkins University Press.

Caves, Richard. 1971. International corporations: The industrial economics of foreign investment. *Economica* 38 (February): 1–27.

Christensen, L.; Cummings, D.; and Jorgensen, D. Forthcoming. An international comparison of growth of productivity, 1947–73. In *New developments in productivity measurement and analysis.* Chicago: University of Chicago Press.

Cooper, Richard. 1972. Technology and U.S. trade: A historical review. In *Technology and international trade.* Washington, D.C.: National Academy of Engineering.

Council of Economic Advisers. 1979. *Annual Report.* Washington, D.C.: Government Printing Office.

Davidson, W., and Harrigan, R. 1977. Key decisions in international marketing: Introducing new products abroad. *Columbia Journal of World Business* (Winter).

Denison, Edward. 1962. *The sources of economic growth in the United States.* New York: Committee for Economic Development.

———. 1967. *Why growth rates differ.* Washington, D.C.: The Brookings Institution.

———. 1978a. Effects of selected changes in the institutional and human environment upon output per unit of output. *Survey of Current Business* (January).

———. 1978b. The puzzling drop in productivity. *Brookings Bulletin* (fall): Washington, D.C.: The Brookings Institution.

Enos, John. 1958. A measure of the rate of technological progress in the petroleum refining industry. *Journal of Industrial Economics* (June).

Evenson, Robert. 1968. The contribution of agricultural research and extension to agricultural production. Ph.D. diss. University of Chicago.

Freeman, Christopher. 1974. *The economics of industrial innovation.* Baltimore: Penguin.

Freeman, Richard. 1971. *The market for college-trained manpower.* Cambridge: Harvard University Press.

Grabowski, Henry. 1976. *Drug regulation and innovation.* Washington, D.C.: American Enterprise Institute.

Griliches, Zvi. 1964. Research expenditures, education, and the aggregate production function. *American Economic Review* 54 (December): 961–74.

———. 1972. A memorandum on research and growth. In *Research and development and economic growth productivity.* Washington, D.C.: National Science Foundation.

———. Forthcoming. Returns to research and development in the private sector. In *New developments in productivity measurement and analysis.* Chicago: University of Chicago Press.

Grossman, M., and Fuchs, V. 1973. Intersectoral shifts and aggregate productivity change. *Annals of economic and social measurement.* New York: National Bureau of Economic Research.

Hansen, W. L. 1967. The economics of scientific and engineering manpower. *Journal of Human Resources* (spring).

Hollander, S. 1965. *The sources of increased efficiency.* Cambridge: M.I.T. Press.

Hsia, Ronald. 1973. Technological change in the industrial growth of Hong Kong. In *Science and technology in economic growth*, ed. B. Williams. London: Macmillan.

Hufbauer, Gary. 1970. *Synthetic materials and the theory of international trade.* London: Duckworth.

Kendrick, John. 1976. Productivity funds and prospects. In *U.S. economic growth from 1976 to 1986.* Washington, D.C.: Joint Economic Committee of Congress (1 October).

Klein, Burton. 1979. The slowdown in productivity advances: A dynamic explanation. Cambridge: Center for Policy Alternatives, M.I.T. (15 January).

Kutscher, R.; Mark, J.; and Norsworthy, J. 1977. The productivity slowdown and the outlook to 1985. *Monthly Labor Review* (May).

Mansfield, Edwin. 1968a. *Industrial research and technological innovation.* New York: Norton. Published for the Cowles Foundation for Research in Economics at Yale University.

———. 1968b. *The economics of technological change.* New York: Norton.

———. 1976. Federal support of R and D activities in the private sector. In *Priorities and efficiency in federal research and development.* Washington, D.C.: Joint Economic Committee of Congress (29 October).

———. 1977. The diffusion of eight major industrial innovations in the United States. In *The state of science and research*, ed. N. Terleckyj. Boulder: Westview.

———. 1980. Basic research and productivity increase in manufacturing. *American Economic Review*. In press.

Mansfield, Edwin, and Romeo, Anthony. In press. Technology transfer to overseas subsidiaries of U.S.-based firms. *Quarterly Journal of Economics*.

Mansfield, Edwin; Romeo, Anthony; and Wagner, Samuel. 1979. Foreign trade and U.S. research and development. *Review of Economics and Statistics* 61 (February): 49–57.

Mansfield, Edwin; Teece, David; and Romeo, Anthony. 1979. Overseas research and development by U.S.-based firms. *Economica* (May).

Mansfield, Edwin, et al. 1971. *Research and innovation in the modern corporation*. New York: Norton.

———. 1977a. *The production and application of new industrial technology*. New York: Norton.

———. 1977b. Social and private rates of return from industrial innovations. *Quarterly Journal of Economics* 91 (May): 221–40.

Minasian, Jora. 1969. Research and development, production functions, and rates of return. *American Economic Review* 59 (May): 80–85.

Nason, H.; Steger, J.; and Manners, G. 1978. *Support of basic research by industry*. Washington, D.C.: National Science Foundation.

National Academy of Engineering. 1976. *Technology transfer from foreign direct investment in the United States*. Washington, D.C.: National Research Council.

National Commission on Technology, Automation, and Economic progress. 1966. *Report to the President of the United States*. Washington, D.C.: Government Printing Office.

National Science Foundation. 1976. *National patterns of R and D resources, 1953–76*. Washington, D.C.: Government Printing Office.

———. 1977. *Science indicators, 1976*. Washington, D.C.: Government Printing Office.

———. 1978. *An analysis of federal R and D funding by function*. Washington, D.C.: Government Printing Office.

———. 1979a. National R and D spending expected to exceed $57 billion in 1980. *Science Resources Studies Highlights* (8 May).

———. 1979b. Total federal R and D growth slight in 1980 but varies by budget function. *Science Resources Studies Highlights* (25 June).

———. 1979c. *Projections of science and engineering doctorate supply and utilization, 1982 and 1987*. Washington, D.C.: Government Printing Office.

Nelson, Richard; Peck, Merton; and Kalachek, Edward. 1967. *Technol-*

ogy, economic growth, and public policy. Washington, D.C.: The Brookings Institution.

Nordhaus, William. 1972. The recent productivity slowdown. *Brookings Papers on Economic Activity*. Washington, D.C.: The Brookings Institution.

Organization for Economic Cooperation and Development (OECD). 1968. *Gaps in Technology*. Paris: Organization for Economic Cooperation and Development.

Perry, George. 1971. Labor structure, potential output, and productivity. *Brookings Papers on Economic Activity*. Washington, D.C.: The Brookings Institution.

Pindyck, Robert. 1979. Should the federal government subsidize synthetic fuels? Testimony before the Senate Committee on Banking, Housing, and Urban Affairs (25 July).

Schwartz, Mark. 1979. The imitation and diffusion of industrial innovations. Ph.D. diss. University of Pennsylvania.

Stobaugh, R., and Yergen, D. 1979. Testimony before the Senate Subcommittee on Conservation and Solar Applications (27 July).

Terleckyj, Nestor. 1974. *Effects of R & D on the productivity growth of industries: An exploratory study*. Washington, D.C.: National Planning Association.

Tilton, John. 1971. *International diffusion of technology: The case of semiconductors*. Washington, D.C.: The Brookings Institution.

Vernon, Raymond. 1966. International investment and international trade in the product cycle. *Quarterly Journal of Economics* (May).