On the advancement of science and technology among nations: the importance of government policies upon the development of advanced technology industries in five countries

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ON THE ADVANCEMENT OF SCIENCE AND TECHNOLOGY AMONG NATIONS: THE IMPORTANCE OF GOVERNMENT POLICIES UPON THE DEVELOPMENT OF ADVANCED TECHNOLOGY INDUSTRIES IN FIVE COUNTRIES

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ABSTRACT

The aims of this study were to compare the importance of government policies upon the development of advanced technology industries in five countries: France, West Germany, the United Kingdom, the United States of America and Japan. Three advanced technology industries were selected: microelectronics, machine tools and advanced materials.

Data were collected from governments in the five countries, academia, independent research organizations, trade associations, industry and international organizations. The data were analyzed using statistical procedures and the results were related to classical and the "new" theories of comparative advantage determinants for the five countries. Critical analysis was also undertaken of the theories that postulate the role of government policies for industrial growth in the light of the rapid geographic diffusion of advanced technology sectors across national boundaries.

As a result of these analyses the role of government policies upon the development of advanced technology industries was identified in the five countries. Analyses were undertaken to determine government policies that were successful and those that were not and the reasons for the success or failure of these policies in the light of economic, social, political and geographic factors.

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A complete list of individuals interviewed is presented in Appendix A.

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CHAPTER 1:

INTRODUCTION

1.1 OVERVIEW

1.1.1 Background

Early studies of what were to become the disciplines of economic geography, economics and international trade identified such geographic variables as land, climate, location and others as the principals determinants of why some nations excel in the production of certain products while others do not. David Ricardo's explanation as to why Portugal produced wine and the United Kingdom manufactured cloth, published in 1915, is an example of an early analysis of geographic characteristics as the determinants of a nation's comparative advantage over others in certain products. Other studies by Ricardo, Daniel Defoe, Joseph Stuart Mill and Alfred Marshall, all appearing before 1990, added labour supply, skills of labour and availability of capital as factors that determine a nation's comparative advantage in the production and commerce of certain products. Furthermore, it became apparent that such comparative advantage resulted in comparative economic power which, in turn, allowed the power to act on the international stage, a key consideration of political geography.

In the ensuing first half of this century these early observations and analyses on a nation's comparative advantage evolved into the classical economic and international trade theories. According to these theories a nation's comparative advantage evolves from the characteristics of three variables: a) the endowment of natural resources, dictated by geographic factors (referred to as "land" in the terminology of classical economic theory); b) the availability and quality of labour; and c) the availability of capital. A common characteristic of these three variables is that they cannot be significantly altered by government policies. The endowment of a natural resource in a country cannot be changed and depends on the geographic factors. Labour and capital resources in a nation may be altered, but such alteration requires time and is essentially constrained by the availability of natural resources, size, location and the other geographic characteristics of a nation.

Therefore, one of the cardinal conclusions of the classical economic theory is that a nation's comparative advantage is best achieved without government intervention of any kind in a country's free functioning markets. The classical economic theory has been contradicted by international trade flows during the last several decades. This phenomenon is of potentially crucial importance for political, geography theory, and particularly geopolitics.

Undisputable statistical information indicates that during the last few decades, but notably since 1980, the industrialized nations of Western Europe and the United States of America (U.S.) have lost significant proportions of the world market share of a number of products embodying some of the most advanced technologies in which these nations had a distinct comparative advantage. These products include a full range of microelectronic goods, computing machinery, advanced machine tools, advanced ceramics and advanced polymers.

Japan and the newly industrialized countries (NIC's), such as South Korea, Taiwan, Hong Kong and Singapore, have gained export markets in these advanced products at the expense of Western Europe and the U.S., and Japan has established a comparative advantage in some of these products. Accompanying losses in world markets for advanced technology products are a number of other factors, which may diminish scientific, technological and economic advancements in Western Europe and the U.S.

It has been alleged in recent economic analyses referred to as the "new" economic theory of comparative advantage that some of these losses can be traced to the absence of appropriate government science, technology and industry policies in these countries (Krugman, 1983).

Moreover, it has been alleged that the application of appropriate government policies may create comparative advantage for some of the advanced technology products in certain nations (Griliches and Lichtenberg, 1984). It has also been stated that Japanese government policies in particular have made a cardinal contribution to the emergence of Japan as a major power in the international trade of advanced technology products, in spite of the fact that such policies are considered by many governments that subscribe to the classical economic theory, to be damaging to national economic growth (Gruber and Vernon, 1970).

1.1.2 Aims

This thesis aims to investigate the extent to which the prescriptions of classical economic theory remain a valid way of explaining current patterns of international trade. More specifically, this thesis argues that rather than government intervention being irrelevant or even harmful to a nation's industrial performance (as maintained by classical economic theory), appropriate government policies can, given the right social and political environment, establish and maintain a comparative advantage for a nation in the production of certain goods. Thus this thesis offers statistical and analytical evidence in support of the proposition that "new," rather than classical economic theory, more accurately reflects the realities of recent and current international trade patterns. Implicit in this argument is the assertion that the traditional determinants of a nation's economic strength, such as natural resources, land, and climate have declined in importance, and that the lack of such natural endowments, can be overcome by appropriate government policies.

1.1.3 Areas of Concentration

For analysis, five countries were selected to represent the spectrum of relations with regard to government science and technology policies: **France, West Germany (hereinafter Germany), the United Kingdom (U.K.), the United States (U.S.), and Japan.** The governments in Germany, the U.K., and the U.S. operate more or less within the framework of the classical economic theory that judges governmental intervention in the free market (both domestic and international) as a futile effort to improve a nation's economic well-being that eventually leads to a decline in the economic growth of the society (Gremmen and Vallenbergh, 1986).

Japan, on the other hand, has enacted a continuous and comprehensive set of policies that have deliberately intervened in both domestic and international markets on behalf of Japanese enterprises (Johnson, 1982). To a certain extent, the Japanese followed some of the prescriptions of the "new" economic theory of international trade, although it would not be incorrect to state that the "new" theory of international trade was developed as the result of Japan's successes in increasing the rate of its economic growth (Lutz and Green, 1983; Krugman, 1984).

While the governments of Germany, the U.K., and the U.S. have in general subscribed to a non-interference approach regarding their industry sectors, French governments have embarked on programmes of selective intervention and Japanese governments have intervened consistently and comprehensively in advanced technology sectors in Japan.

The five countries selected belong to the Group of Seven leading industrial countries. Italy and Canada represent the other two nations in the Group of Seven. However with regard to the specific advanced technologies selected for the analyses, both Italy and Canada may be regarded as marginal performers and are therefore omitted.

The focus of the analysis is on the advanced technology end of the economic activity spectrum, specifically:

a) microelectronics,

b) advanced machine tools, and

c) a group of advanced materials consisting of three distinct product lines (advanced ceramics, materials based on polymers and composites).

The selection of these three advanced technologies is based on their worldwide importance in general, and their use in the manufacture of essential products in particular. To a very significant degree this importance stems from the fact that these three advanced technologies are essential for the manufacture of most other goods and/or the provision of most essential services.

They include all communications, segments of transportation, metal forming activities, the manufacture of airplanes, office equipment, machinery as well as industrial and household end-products. In fact, these three technologies represent a major portion of the "building blocks" for a nation's economic base. Potentially, therefore, they exercise an important influence on a nation's power to act internationally, its foreign policy implementation.

There three technologies have also been subjected to a continuous stream of innovations. The 'intellectual distance' for these three technologies, between scientific endeavors in he research laboratories and their technologies use in the market place, is very short.

The salient economic characteristics of the three advanced technology sectors which were deliberately selected as being very different, are discussed below.

The microelectronics sector, which in 1988 accounted for worldwide sales of $47 billion, represents very recent technology, which began with the discovery of the transistor by B. Kilby and Robert Noyce in 1961 (Sterling Hobe Corporation (SHC), 1974). Most industrialized nations are engaged in the research, development, design, engineering, manufacture and sales of microelectronic products (Office of Technology Assessment (OTA), 1965). Microelectronic products represent intermediate products for a large number of other important advanced technology goods. Further, microelectronic intermediate products represent a very large proportion of the total value of the various end products which embody microelectronic components. For example, microelectronic components represent approximately 67 percent in value of all computers; 46 percent in value of communications systems; 56 percent of all radio, TV and broadcasting apparatus; and about 60 percent in value of scientific measuring instruments, (SHC, 1988). The total value of microelectronic goods traded in international markets in 1988 was estimated at $30 billion (SHC, 1988).

The advanced machine tools sector results from the merging of a very old industry sector, metal working machinery (begun in the 1880's) with the microprocessor and other microelectronic components sectors (ITC, 1983).

The success of this merger has varied among industrialized nations. Some of the industrialized countries which began and excelled in metal working machinery have a relatively poor record in combining the old so-called "iron" portion of machine tools with the microelectronics components. The U.S. and the U.K. are examples of this (OTA, 1985). Other nations, notably Japan and Germany, have had considerable success in merging metal cutting segments of machine tools with microelectronic components. International trade in advanced machine tools is large (in 1986 it was valued at $30 billion) and increasing.

Advanced materials represent a relatively large group of commodities with significant differences in their chemical and physical composition and methods of manufacture (U.S. National Academy of Science (NAS), 1986). The common characteristic among all advanced materials is their superior critical use properties such as hardness, working temperatures, damage tolerance, resistance properties to corrosion, high specific strength, and fatigue resistance of importance to many advanced technology products including military hardware (NAS, 1986). Often, the critical use characteristics of advanced materials are an improvement on conventional materials by a factor of 30 to 50 (OTA, 1984). For the analysis, the three most advanced, but different types of advanced materials in terms of manufacturing technologies and types of market demand, have been selected:

1) advanced ceramics,
2) advanced polymers, and
3) composites.

In contrast to microelectronics and advanced machine tools, most of the industrial activities focused on advanced materials <u>remain in the research and development phase</u> (NAS, 1985). Few advanced materials have yet reached the market place. Domestic and international trade in advanced materials is therefore marginal (OTA, 1984). However, all industrialized nations engage in the research, development and engineering of these materials (NAS, 1986). Thus, at this stage, significant government policies are vital to encourage the further development of advanced materials.

The three technologies selected represent three phases of a manufacturing industry. In the case of advanced materials, this sector is in the very early stages of development representing an industry sector in its initial phase with a history of less than a decade.

The microelectronics industry sector has a history of about twenty years and represents an industry sector with very rapid technological advancement as well as very rapid increases in production and markets.

The advanced machine tools sector represents a very old industry, begun essentially at the time of the Industrial Revolution during the second half of the last century. This sector is an example of a countinously evolving and advancing technology.

The genesis of these three technology categories (microelectronics, machine tools and advanced materials) and the initial technological development, took place in four countries: 1) France; 2) Germany; 3) the U.K.; and 4) the U.S.

Within a period of the past three decades, Japan, and to a lesser extent other countries, were able to transfer these advanced technologies to their indigenous industry, often to advance these technologies, and to compete in the world's markets with them.

1.2 OUTLINE OF THE THESIS

A total of fourteen chapters and three appendices comprise the thesis. Chapter 2 analyzes the intensity, status and trends in the scientific, research, development and engineering activities of the five countries. The objective of this analysis is to present information on the resources committed to the scientific activities which result in the advanced technology products. A number of statistical measures of activities related to science and technology are presented and a comparative analysis of these is undertaken.

Chapter 3 consists of three parts. The initial part presents a critical review of the classical economic and international trade theory. The second part presents selected statistical data and an analysis of international trade with the emphasis on advanced technology products for the five countries included in this analysis. The objective of this presentation is to indicate the changes in international trade patterns for these nations, in the light of the public policy prescriptions as contained in the theory of classical economics.

The final section in Chapter 3 presents a critical appraisal of the "new" theories of economic policy and international trade that reflect the empirical evidence on international trade presented in the previous section.

Chapter 4 presents a discussion on the concepts of science and technology as these are used in public policy formulation and examines the government policies used to obtain alleged benefits to the domestic industry sectors.

Chapters 5, 6, and 7 present a detailed assessment of the status of three three industry sectors:

1. microelectronics
2. advanced machine tools
3. advanced materials.

The latter category is subdivided into three product subgroups:

1. advanced ceramics
2. materials based on polymers and
3. composites.

These chapters essentially consist of case studies in which the development and current status of each of the three technologies is presented for each of the five nations. The analysis is accompanied by relevant statistical information.

The objective of these seven chapters is to provide factual information, supported by analyses of the status of science and technological achievement in the five selected countries.

Chapters 8 to 12 present, on the basis of analyses undertaken in the previous chapters, a critical appraisal of government policies in each of the five nations in the light of its current status regarding the international competitiveness of advanced technologies. In each of these chapters, the appraisal is initiated by a critical discussion of government and private sector activities that comprise science and technology policy in the light of the historic, economic and institutional setting for each of the five selected nations.

Analyses which follow include both general science and technology policies, as well as industry specific policies. Geographic, economic and social variables for each of the five nations, which affect governments' policies are also presented and analyzed. The most likely short-term implications regarding the international competitiveness of these three technologies for these five nations are presented at the conclusion of each of these chapters.

Chapter 13 presents a summary of the factual information contained in this thesis and offers conclusions based on this information. Chapter 14 considers some of the probable future developments regarding the three advanced technology sectors for each of the selected countries.

Appendix A contains a listing of individuals contacted during the three years of thesis preparation. Without their kind cooperation, the preparation of this thesis would have been impossible, and their assistance is very much appreciated. Appendix B contains a glossary of technical terms. The bibliography is in Appendix C.

1.3 METHODS AND SOURCES

The methodology used in Chapter 2, that of presenting the current status and historical trends of science and technology in the selected nations, consists of reducing raw data into the form of various indices, ratios, unit expenditure measures and other quantitative comparisons to illustrate science and technology trends in a quantitative manner.

The principal data for these presentations were obtained from the following sources:

National Science Foundation, USA (NSF)
U.S. Department of Commerce (DoC)
Office of Technology Assessment, USA (OTA)
Organization of Economic Cooperation and Development Science and Technology Directorate, Paris, France (OECD)
Commission of the European Communities, Brussels, Belgium (CEC)
Ministry of International Trade and Industry, Tokyo, Japan (MITI)
Ministry of Finance, Tokyo, Japan (MoF)

Centre d'Etudes Prospectives et d'Informations Internationales (CEPII)
Institut fur Westwirtschat, Bonn, Germany
Ministere de l'Industrie, Paris, France (MI)
Department of Trade and Industry, London, England (DTI)
Ministre de la Recherche et de la Technologie, Paris, France (MRT)
Statistisches Bundesant, Bonn, Germany (SB)
Bundesministerium fur Forschung und Technologie, Bonn, Germany (BFMT)

Secondary information was obtained from the Massachusetts Institute of Technology, Public Policy Unit; the University of Sussex, Science Policy Research Unit; the Institute fur Weltwirtschaft, Kiel, Germany; the University of Tokyo, Japan; the Max-Planck Gesellschaft, Munich, Germany; Universite de Technologie at Compaigne, France (UTC); Ecole des Mines, Paris, France (EM); and Sophia University, Tokyo, Japan.

The methodology in Chapter 3 is that of a conventional critical review of pertinent literature; of the principal theoretical and empirical analyses which set forth the classical economic theory for economic policy and of the "new" economic policy theories. The review includes comments and rejoinders of these analyses.

The methodology used for the presentation of the international trade analysis in Chapter 3 consists of simple statistical analyses of international trade data. The principal sources for the data are international trade printouts from the OECD; the U.S. DOC; the International Trade Administration (ITA); Japan's MoF; the U.K. DTI; and the CEPII.

The methodology used in Chapter 4 is that of the critical review of legal documents pertaining to import-export licenses and of studies that have analyzed economic and international trade regulations in various countries.

Certain critical issues arising from the literature review were augmented with interviews. The interviews conducted were with individuals associated with academic institutions and government officials. These are listed in Appendix A.

Chapters 5, 6, and 7 undertake case studies of the three technologies selected for each of the five countries. Several advanced technology market analysis firms, such as Dataquest; EEC Corporation; Varrian Associates; and ICE Corporation, collect and publish information on advanced technology sectors for the OECD member nations. Information from these sources was used in these chapters.

Other principal data sources included government laboratories such as the National Bureau of Standards, U.S.; Nippon Electronic Company's Laboratories, Tokyo, Japan; the National Institute for Research of Inorganic Materials, Ibaraki, Japan; Technical Department, Ceramics Division, Showa Denko, K.K., Tokyo, Japan; Teijin Limited, Tokyo, Japan; the Institut National de Recherche en Information et en Automatique, Paris, France; Systems Informatiques de la Connaissance (SICO), Paris, France; the Science and

Engineering Research Council, the United Kingdom; Deutsche Forchungsgemeinschaft, Germany; Centre National de la Recherche Scientifique, France; and the Institut Universitaire de Technologie, France.

Considerable use was made of the very comprehensive data base on the world-wide machine tool industry maintained by the U.S. National Machine Tool Builders Association (NMTBA). Much of the required information was published in the various issues of American Machinist. A significant portion of the required data was available only from data printouts maintained and processed by the NMTBA.

A very large proportion of data on the microelectronics industry in various countries was obtained from the U.S. Semiconductor Industry Association (SIA).

Certain information on international trade and on domestic industrial trends was obtained from the U.S. DOC and Japanese MOF data printouts.

In the presentation of advanced ceramics, polymers and composites technologies, much of the information used was obtained from academic institutions and government laboratories in the five countries identified above. Certain information on the advances in these technologies could not be presented, however, because the advances are funded by the U.S. Department of Defense (DOD), and thus much of the information is restricted.

Chapters 8, 9, 10, 11, and 12 present critical analyses of government science, technology, and industry policies in the five countries. Principal information sources were the libraries and archives of the U.S. International Trade Commission, the U.S. Department of State, and the U.S. Executive Office of the President, Special Trade Representative.

Chapter 13 presents conclusions of the research presented for this thesis and Chapter 14 identifies future prospects for advanced technology industries.

FOOTNOTES TO CHAPTER 1

(1) Reductions in the elapsed time between the scientific discovery of new technologies and products and their application in the market place are very important considerations for government and industry policies. See, for example:

Joel Calton and Stuart Bruchey (eds.), Technology, the Economy, and Society, Columbia University Press, New York, 1987.

CHAPTER 2:

SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES IN FRANCE, GERMANY, THE UNITED KINGDOM, THE UNITED STATES AND JAPAN

2.1 INTRODUCTION

Natural and man-made endowments in any nation represents an important factor in that nation's economic performance. During the time of the initial development of systematic economic theory, the composition of a nation's endowment was described as land, labour, and capital, with geographic variables other than land, as additional critical elements. David Ricardo's example of the natural endowments of Portugal as opposed to those of England for the manufacture of cloth illustrates this point (Deardorff, 1979).

Over time the concepts of a nations' endowments were blended by economists into the term "national characteristics". This term describes the combination of climate, land, capital, human resources, educational attainment of the population, labour force skills, etc., that represent the unique "bundle" of resources required to establish comparative advantages in a nation (Bowen, 1983).

National characteristics of a country are one of the determinants of economic power (Bowen, 1980a; Hieronymi, 1980; Schumpeter, 1943). The national characteristics of a country determine comparative advantage for industry sectors that govern industrial development and establish principal industry sectors as well as determining the characteristics of a nation's industry base. A country's industry base in turn determines the economic power of a nation. The economic power allows for changes in national characteristics. Such changes may take a significant amount of time to take effect, but may be nevertheless effectively implemented by the appropriate use of the economic power. For example, the very rapid technological advancement of the Japanese microelectronic industry sectors, has provided Japan with absolute comparative advantage in several key components of Japan's industrial base (Moritari, 1983). This in turn has allowed the Japanese to demand from foreign governments that Japanese microelectronic product manufacturing facilities located in foreign countries be allowed to undertake all research and development activities in Japan rather than in the nations where the Japanese manufacturing facilities are located. The result of this use of the economic power by the Japanese government has been a significant increase in research and development activities in Japan and the overall improvement of the Japanese technological base.

Clearly, national characteristics play a role in shaping the growth of a nation's economy and the pattern of international trade. However, the present pattern of trade suggests that traditional national characteristics alone cannot explain the present pattern of international trade.

As Krugman (1983) states:

> Since World War II, however, a large and generally growing part of world trade has come to consist of exchanges that cannot be attributed so easily to underlying advantages of the countries that export particular goods. Instead, trade seems to reflect arbitrary or temporary advantages resulting from economies of scale or shifting leads in close technological races.

Krugman goes on to state that it is the technological base of a nation which plays a major role in the determination of a country's ability to increase its economic production and international trade.

> We should also note a related change in international trade. Among the forces that seem to be driving international specialization, an increasingly important one seems to be technology. In many industries competitive advantage seems to be determined neither by underlying national characteristics, nor by the static advantages of large-scale production, but rather by the knowledge generated by firms through R&D and experience. As we have already noted, however, technological innovation is an activity that may well generate important spillovers to the rest of the economy. Its growing importance in international trade thus reinforces the need for a rethinking of the analtyical basis for trade policy (Krugman, 1983).

The relationship between technological advances and a nation's economic growth is, however, difficult to quantify, as stated by Griliches (1984):

> The evidence of the economic impact of science and technology is all around us. Most of us also share the conviction that both the public investment in science and the private investments in industrial R&D have been crucial contributors to world economic growth in the past and remain crucial as far at the future is concerned and the role of the United States in it. Nevertheless, the quantitative, scientific base for these convictions is rather thin. The anecdotal and historical evidence is adequate to establish the main facts of the matter, but it is insufficient for advising on whether the current level of investments in science and technology is too large or too small, or discerning whether the returns to such investments have declined over time and for what type of investments, if any. Any attempt to answer such questions in a quantitative manner requires the examination of the recent history of economic growth in this country and the role of science and industrial R&D in it. This turns out much harder than one might have expected, both because of the difficulties in measuring economic growth and the contributions of science and technology to it and because of the more general problem of estimating behavioral relations and inferring causality from aggregate nonexperimental economic data.

However, the common consensus among economists, government officials, and industry executives is that the impact of science and technology on the economy is substantial. For example, the role of technology as the critical element in a nation's economy and international trade is cited by W. Michael Blumental, Secretary of the United Sates Treasury from 1977 to 1979 (Blumenthal, 1988).

Most other economists argue that the intensity of science activities in any one nation determines the level of technology utilized by that country in the manufacture of goods and provision of services (Adams et al, 1983; Balassa, 1986).

The intensity of science activities impacts not only on a nation's domestic economy, but equally importantly on a nation's international competitive advantage and therefore, export potential. The impact of R&D expenditure on a nation's export performance has been acknowledged by many, among them, Gruber, Mehta and Vernon (1967) who state:

> All roads lead to a link between export performance and R&D. Whether one accepts the cheap-skilled-labor hypothesis of Leontief or the alogopoly hypothesis in the tradition of Williams, one expects to see a link between exports and research effort.

This chapter, therefore, provides a comparison of science activities among the five industrialized countries selected for study: France, FRG, the U.K., U.S. and Japan.

Most of the economists, geographers and political scientists regard these five nations as the principal industrial countries in the world. Muir (1975), for example, categorizes the U.S. as a "superpower," the U.K., Germany and Japan as "great powers;" France receives only "power" designation from Muir.

German (1960) developed an index of world power combining such measures as area of a state; population, economy, transportation and industrial strength. The grand totals, combining all types of measures, gave this final result for the top five most powerful nations:

The U.S.	-	6,459;
USSR	-	6,321;
The U.K.	-	1,257;
China	-	999; and
Germany	-	664.

Note that Japan and France are not included in the top five nation rankings, as reported by German. Karl Deutch (1963) using a formula based on economic production obtained the following ranks for 1963; the U.S. was equal to 100, with USSR second at 68, China at 26, Germany at 14, Japan at 12, and the U.K. at 11. Another index that included the components of technology trade and military power was released in 1970. The top six nations, for the year 1970, results in the following ranking (based on the percentage received out of 100.0 percent (Saatz and Khouja, 1976):

The U.S.	o	409
USSR	o	163
Japan	o	134
Germany	o	116
France	o	077
The U.K.	o	072

Clearly, the five selected nations for this thesis have been consistently measured at the top of the industrial countries during the 1950's, 1960's and 1970's.

As presented in this thesis the comparative importance of these nations has undergone significant changes over the last decade.

2.2 COMPARISON OF SCIENCE AND TECHNOLOGY ACTIVIES IN THE SELECTED COUNTRIES

Table 2.1 provides an overview of selected science related variables in the five countries selected for analysis. It also shows indicators of the science and engineering effort relative to the size of each country. For the five countries, total research and development (R&D) as a percent of the GNP is of similar magnitude, ranging from 2.2 percent for the U.K. to 2.8 percent for the U.S. and Japan. For nondefence R&D as a percent of GNP, the range is greater, from 1.5 percent for the U.K. and 1.9 percent for the U.S. and France, to 2.6 percent for Germany and 2.8

percent for Japan. In the U.S., almost 70 percent of government R&D funding is for defence. Because development accounts for about 90 percent of U.S. defence R&D, the importance placed on research is much less.

The U.S. and Japan have the highest number of R&D scientists and engineers per 10,000 persons in the labour force, 69 and 63 respectively, with France and the U.K. at the low end of about 40. For GNP, R&D funding, and the number of R&D scientists and engineers, the U.S. is larger than the total of the other four countries combined.

2.2.1 Resources Devoted to the Science and Techonology Activities

The level of R&D effort in all five countries has increased significantly in the last several decades (Table 2.2 and Figure 2.2).

Relative shares of R&D expenditures as a percent of the GNP for all countries remained more or less constant, and there have been no significant shifts in the distribution of R&D expenditures among the five countries. The U.S. accounts for about half of the total R&D expenditues and Japan for about one-fifth; the other countries spend relatively less on R&D.

Table 2.1

Selected Research and Development Activity Indicators Relative to Country Size; United States, Japan, Germany, France, and the United Kingdom, 1987

INDICATOR	U.S.	JAPAN	GERMANY	FRANCE[1]	U.K.[2]
GNP (in billion constant 1982 dollars)	3680.7	1231.1	682.7	561.3	530.2
R&D (in billion constant 1982 dollars)	102.5	35.4	18.7	13.5	11.8
R&D/GNP Ratio	2.8%	2.8%	2.7%	2.4%	2.2%
Nondefence R&D/GNP Ratio	1.9%	2.8%	2.6%	1.9%	1.5%
Labour Force (in millions)	119.5	60.3	27.7	23.8	27.4
R&D Scientists and Engineers[3] (in thousands)	825	406	135	98	90
R&D Scientists and Engineers per 10,000 labour force	69	63.2	49.1	41.2	32.8

1 - Data for France use gross domestic product.
2 - Data for the U.K. are for natural sciences and engineering only.
3 - Scientists and engineers engaged in research and development on a full-time basis except Japan, whose data include persons primarily employed in natural science and engineering research and development and the U.K. whose data include only the government and industry sectors.

Source: Adapted from Lederman, 1987.

Data presented in Table 2.3 indicate R&D expenditures for the five selected nations in constant monetary units, that of 1982 U.S. dollars.

As shown, France and the U.S. have approximately doubled their annual national R&D expenditures in real terms during the 1965 to 1987 period. Germany's R&D expenditure in real terms increased by a factor of approximatley three, while the U.K. increased its annual expenditures by a relatively modest 50 percent over the same period. In the case of Japan, its R&D expenditures in real terms increased from about $6 billion in 1965 to $40 billion in 1987, an almost sevenfold increase in two decades.

An analysis of R&D expenditures in market economies must distinguish between defence-related R&D and non-defence R&D. Non-defence R&D is defined as the difference between national R&D expenditures and Government-supported R&D related to defence. Japan and Germany direct relatively high shares of their national income toward non-defence R&D, while the U.S., the U.K., and France spend relatively lower amounts.(1) Although total R&D expenditures have increased substantially in Germany and Japan, government funding of defence R&D has remained quite low. In contrast, in the U.S., France, and the U.K., increases in R&D

Table 2.2

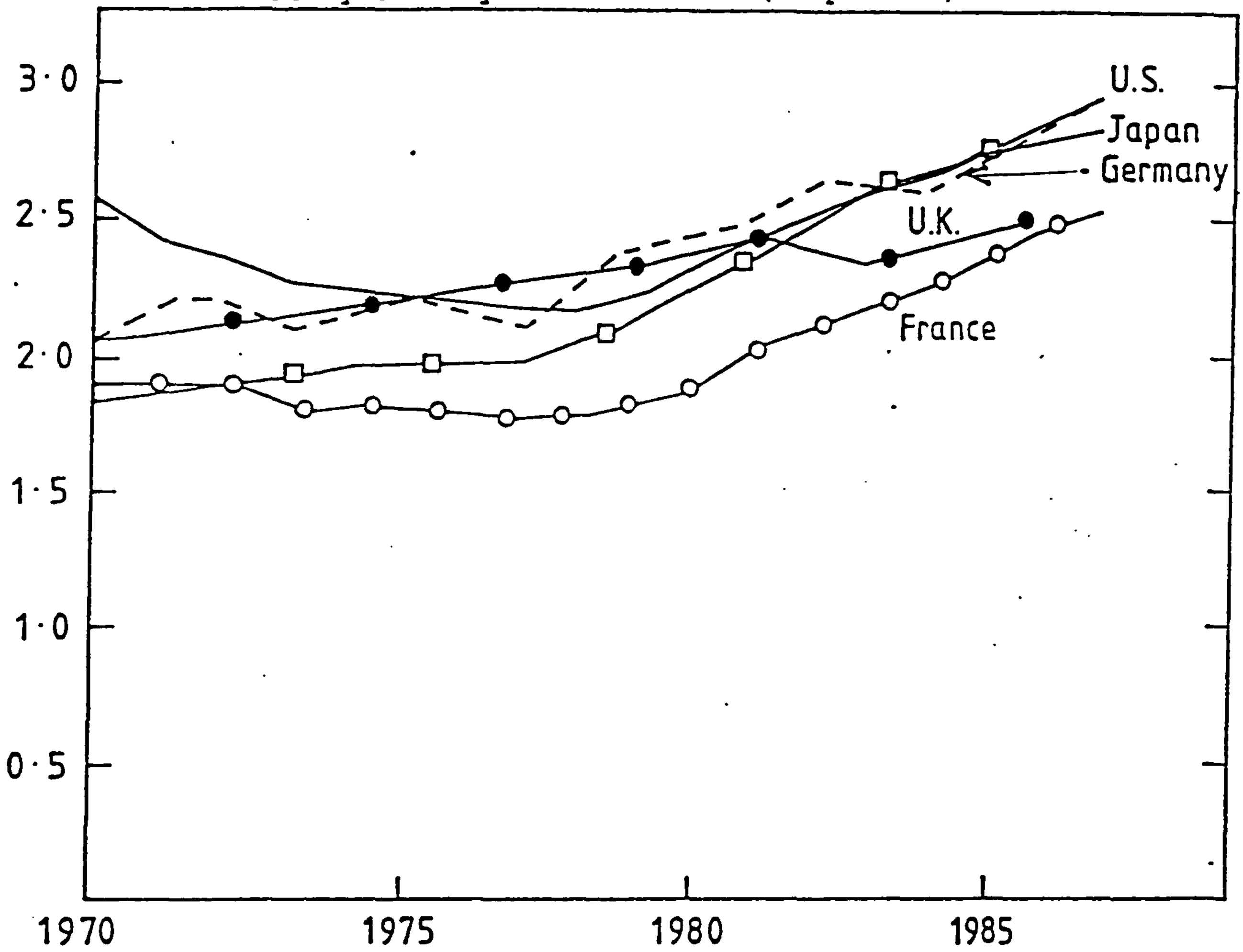
National Expenditures for Performance of R&D as a Percent of Gross National Product (GNP) for Selected Countries: 1961 - 1987

YEAR	FRANCE	GERMANY	JAPAN	UNITED KINGDOM	UNITED STATES
R&D Expenditures to GNP					
1961	1.37	NA	1.39	2.47	2.73
1962	1.47	1.25	1.47	NA	2.73
1965	2.00	1.72	1.52	NA	2.89
1970	1.92	2.06	1.85	2.07	2.63
1975	1.80	2.22	1.96	2.19	2.27
1980	1.84	2.42	2.22	NA	2.38
1981	2.01	2.49	2.38	2.41	2.43
1982	2.10	2.58	2.47	NA	2.58
1983	2.15	2.57	2.61	2.25	2.62
1984	2.22	2.52	2.77	2.42	2.62
1985	2.27	2.67	2.83	NA	2.70
1986	2.41	2.74	2.82	2.23	2.72
1987	2.38	2.73		2.37	2.77
R&D Expenditures (national currency in billions)					
1961	4.5	NA	275.5	0.68	14.3
1962	5.4	4.5	319.3	NA	15.4
1965	9.8	7.9	508.6	NA	20.0
1970	15.0	13.9	1,355.5	1.07	26.1
1975	26.2	23.0	2,974.6	2.30	35.1
1980	51.0	35.9	5,246.2	NA	62.6
1981	62.5	38.4	5,982.4	6.14	71.8
1982	74.8	41.3	6,528.7	NA	79.3
1983	84.7	43.0	7,180.8	6.79	86.6
1984	95.0	44.2	8,890.3	8.15	95.9
1985	104.0	49.0	7,783.9	NA	116.8
1986	117.0	53.4	8,100.0	7.90	124.8
1987	119.8	52.3	8,200.0	7.95E	126.8
1988	120.0	53.0	8,600.0	7.50E	130.0

Source: OECD, Science and Technology Indicators Recent Results, June 1984; National Science Foundation, National Patterns of Science and Technology Resources 1984 (NSF 84-311); and OECD, International Statistical Year, 1983; NSF printouts for 1987 and 1988.

Figure 2.1

National Expenditures for Performance of R&D as a Percent of Gross National Product by Country - 1970 - 1987 (in percent)



Source: U.S. NSF data tapes, 1988

Table 2.3

National R&D Expenditures for the Selected Countries, 1965 - 1987 (Constant 1982 Dollars in Billions)

YEAR	FRANCE	GERMANY	JAPAN	UNITED KINGDOM	UNITED STATES
1965	5.8	6.7	6.1	8.0	59.4
1970	5.3	7.7	12.4	5.7	62.4
1975	8.1	11.9	16.7	10.2	59.9
1980	9.8	15.2	23.1	NA	73.2
1981	10.9	15.8	27.1	11.0	76.6
1982	11.6	15.7	27.4	NA	79.3
1983	11.9	16.1	29.9	11.5	83.9
1984	12.6	16.4	32.5	NA	90.5
1985	12.9	17.8	36.0	11.9	96.5
1986	13.8	18.8	38.7	12.1	100.4
1987	14.7	19.3	40.0	12.7	110.6

Note: U.S. dollar conversions are based on OECD purchasing power parity exchange rates and U.S. Department of Commerce GNP implicit price deflators. Data for the latest years are preliminary or estimated. The latest data for FRG are NSF estimates based on preliminary national data. The U.K. data for 1965 are unavailable; the datum presented is for 1964.

Sources: National Science Foundation, Organization for Economic Co-operation and Development, 1988.

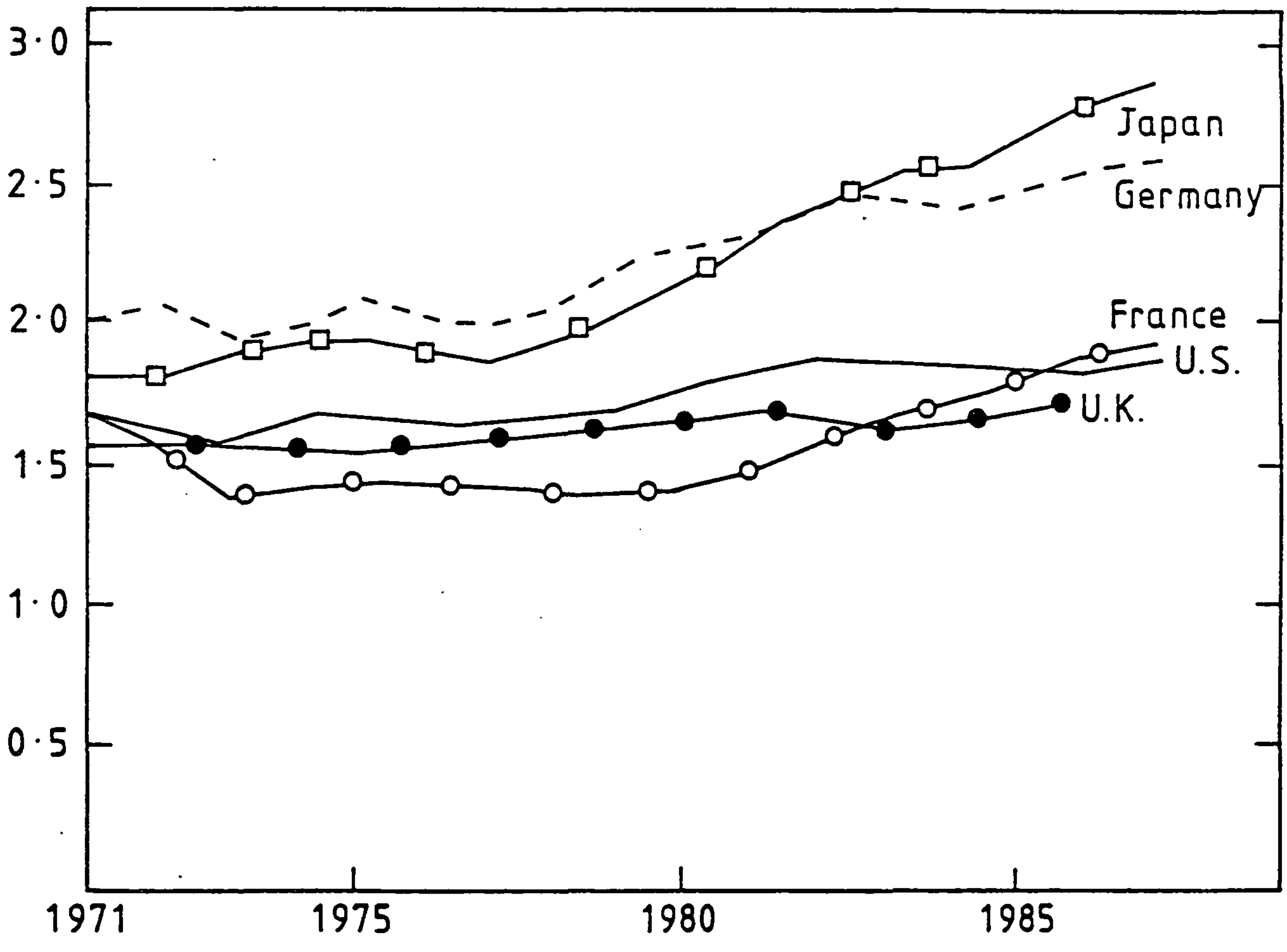
funding were concentrated in defence-related areas during the early and mid-1970's, so that the share of GNP devoted to non-defence R&D was stable or falling. Non-defence R&D has increased relative to GNP only during the last 10 years in these countries.

The ranking of countries by the proportion of GNP which is devoted to non-defence R&D expenditure is similar to the ranking of countries by the percentage of national R&D expenditure which is financed by industry (Figure 2.3). In 1987, about 50 percent of the national R&D effort was financed by private sources in the U.S., in the U.K. and France the percentage was 45, while in Germany and Japan the private shares were 65 and 70 percent respectively. At the same time, funding of defence R&D represented between 49 and 55 percent of total government R&D funding in the U.S., the U.K. and France, but only 9 percent in Germany and 2 percent in Japan.

The low amounts which the governments of Germany and Japan spend on defence R&D reflect, in part, the constitutional constraints placed on them at the end of World War II. While the policies of the U.S., France, and the U.K. have evolved to encourage strong defence capabilities, Japan and Germany maintain small defence R&D efforts, particularly when compared to the strength of their non-defence R&D activities (Table 2.4).

Figure 2.2

Estimated Ratios of Non-Defence R&D
Expenditures to Gross National Product by Country
1971 - 1987 (in percent)



Source: U.S. NSF data tapes, 1988.

Table 2.4

Estimated Ratio of Nondefence R&D Expenditures, as a Percent of GNP for Selected Countries: 1971-86

YEAR	FRANCE	GERMANY	JAPAN	UNITED KINGDOM	UNITED STATES
1971	1.5	2.0	1.8	NA	1.6
1972	1.5	2.1	1.8	1.6	1.6
1973	1.4	1.9	1.9	NA	1.6
1974	1.4	2.0	2.0	NA	1.6
1975	1.5	2.1	1.9	1.6	1.6
1976	1.4	2.0	1.9	NA	1.6
1977	1.4	2.0	1.9	NA	1.6
1978	1.4	2.1	2.0	NA	1.6
1979	1.4	2.3	2.1	NA	1.7
1980	1.4	2.3	2.2	NA	1.8
1981	1.5	2.3	2.4	1.7	1.8
1982	1.6	2.4	2.5	NA	1.9
1983	1.7	2.4	2.6	1.5	1.9
1984	1.8	2.4	2.6	NA	1.8
1985	1.8	2.5	2.8	1.5	1.9
1986	1.9	2.6	2.9	NA	1.8
1987	1.9	2.6	2.9	NA	1.8

Sources: NSF, Organisation for Economic Co-operation and Development, 1988.

Tables 2.5 and 2.6 present salient information on R&D activities undertaken and/or funded by industry in the selected countries. As the information presented in these tables indicates, there have been some increases in the funding and performance of R&D by industry over time for all of the selected countries. These increases, however, have been modest and the pattern of R&D funding and performance by industry remains essentially stable (Figure 2.4).([2])

2.2.2 Scientific and Engineering Personnel

Figure 2.5 compares the relative R&D efforts of the five selected countries, as indicated by the proportion of the total labour force in each country employed as scientists or engineers. These data indicate that during the last decade there have been gradual increases in the employment of scientists and engineers and therefore an increase in R&D activities.

The absolute number of personnel engaged in R&D has increased substantially in all five countries as shown in Table 2.7. Between 1965 and 1987 this number more than doubled in all countries shown, except in the U.S. which employed about 45 percent more research scientists and engineers in 1987 than it did in 1965.

Table 2.5

National R&D Expenditures Financed by Industry
for Selected Countries (Percent)

1970-1987

COUNTRY	1970	1983	1984	1985	1987
United States	40	50	50	50	50
France	37	42	41	41	45
Germany	53	59	60	61	65
Japan	59	65	67	67	70
United Kingdom	42	42	NA	42	45

Sources: National Science Foundation, Organisation for Economic Co-operation and Development, 1988.

Table 2.6

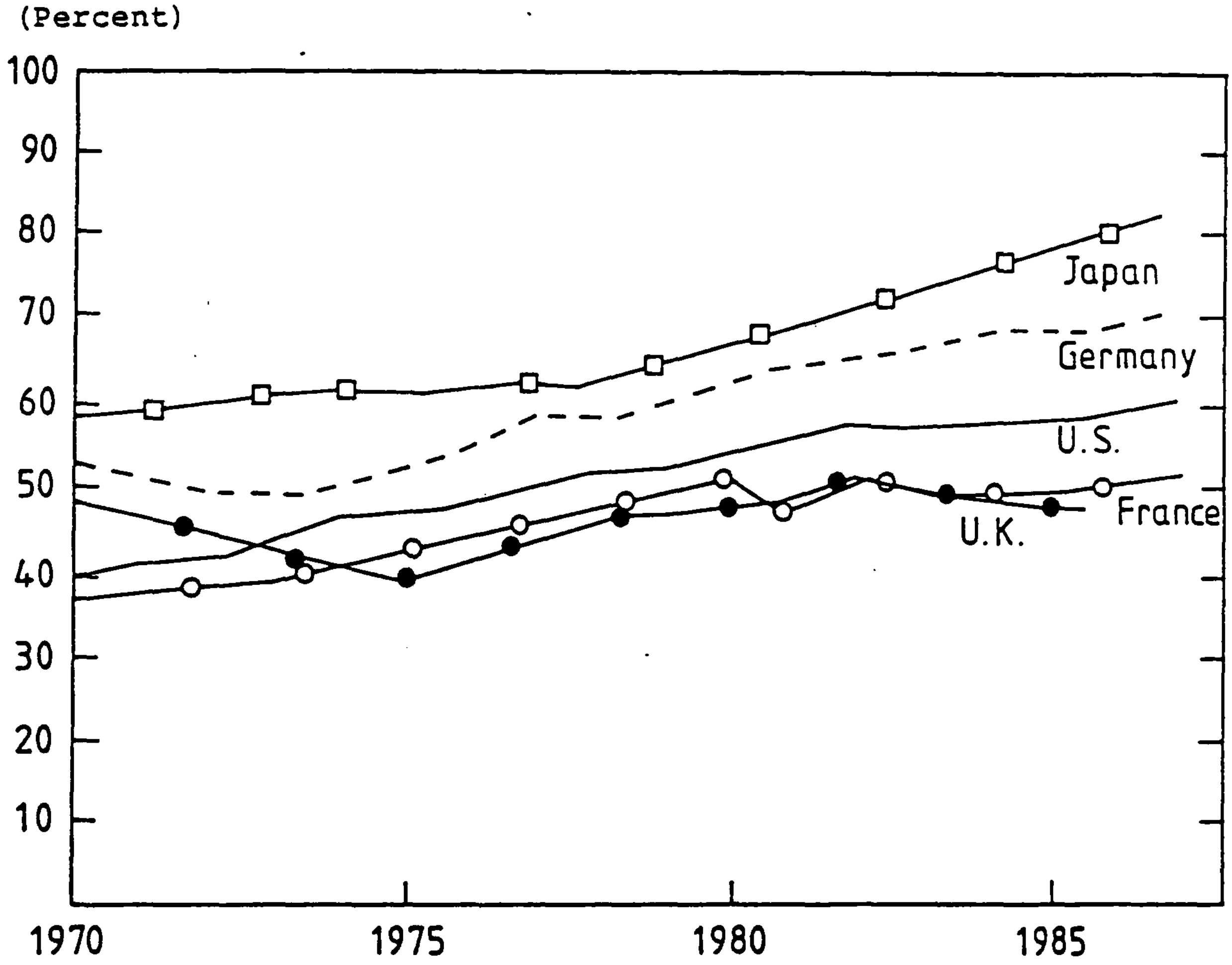
Industry Performance and Funding of Research and Development, for Selected Countries: 1970-87

YEAR	FRANCE	GERMANY	JAPAN	UNITED KINGDOM	UNITED STATES
(R&D Performed by Industry - Millions National Currency)					
1970	8,322	8,900	823,265	NA	18,067
1975	15,617	14,469	1,684,847	1,340	24,187
1976	17,992	15,300	1,882,231	NA	26,997
1980	30,788	NA	3,142,256	NA	44,505
1981	36,805	26,196	3,629,793	3,793	51,810
1982	43,351	NA	4,039,018	NA	57,995
1983	48,098	30,060	4,560,127	4,163	63,405
1984	54,000	NA	5,136,634	NA	71,471
1985	NA	NA	NA	NA	78,181
1986	NA	NA	NA	NA	85,660
1987	NA	NA	NA	NA	90,700
(R&D Funded by Industry - Millions National Currency)					
1970	5,465	7,419	792,970	453	10,444
1075	10,235	11,514	1,715,734	823	15,820
1980	22,269	NA	3,194,604	NA	30,911
1981	25,562	21,860	3,726,055	2,529	35,944
1982	31,157	NA	4,160,607	NA	40,096
1983	35,525	25,144	4,678,482	2,869	43,514
1984	39,200	NA	5,278,564	NA	48,821
1985	43,850	29,841	6,125,416	3,757	52,569
1986	NA	NA	NA	NA	55,699
1987	NA	NA	NA	NA	58,770
(Gross Domestic Expenditures on R&D - Millions National Currency)					
1970	14,956	13,903	1,355,505	NA	26,134
1975	26,203	11,968	2,974,573	2,300	35,213
1980	51,014	35,903	5,246,247	NA	62,593
1981	62,471	37,703	5,892,356	6,134	71,840
1982	71,836	41,300	6,528,701	NA	79,328
1983	84,671	42,512	7,180,781	6,820	87,204
1984	96,198	44,200	7,893,931	NA	97,639
1985	105,917	49,000	8,890,299	8,150	107,642
1986	117,000	53,400	NA	NA	116,793
1987	NA	NA	NA	NA	124,250

Sources: United States: NSF, National Patterns of Science and Technology Resources: 1987 (forthcoming); other countries: OECD, Science, Technology & Industry Indicators Div., 1988.

Figure 2.3

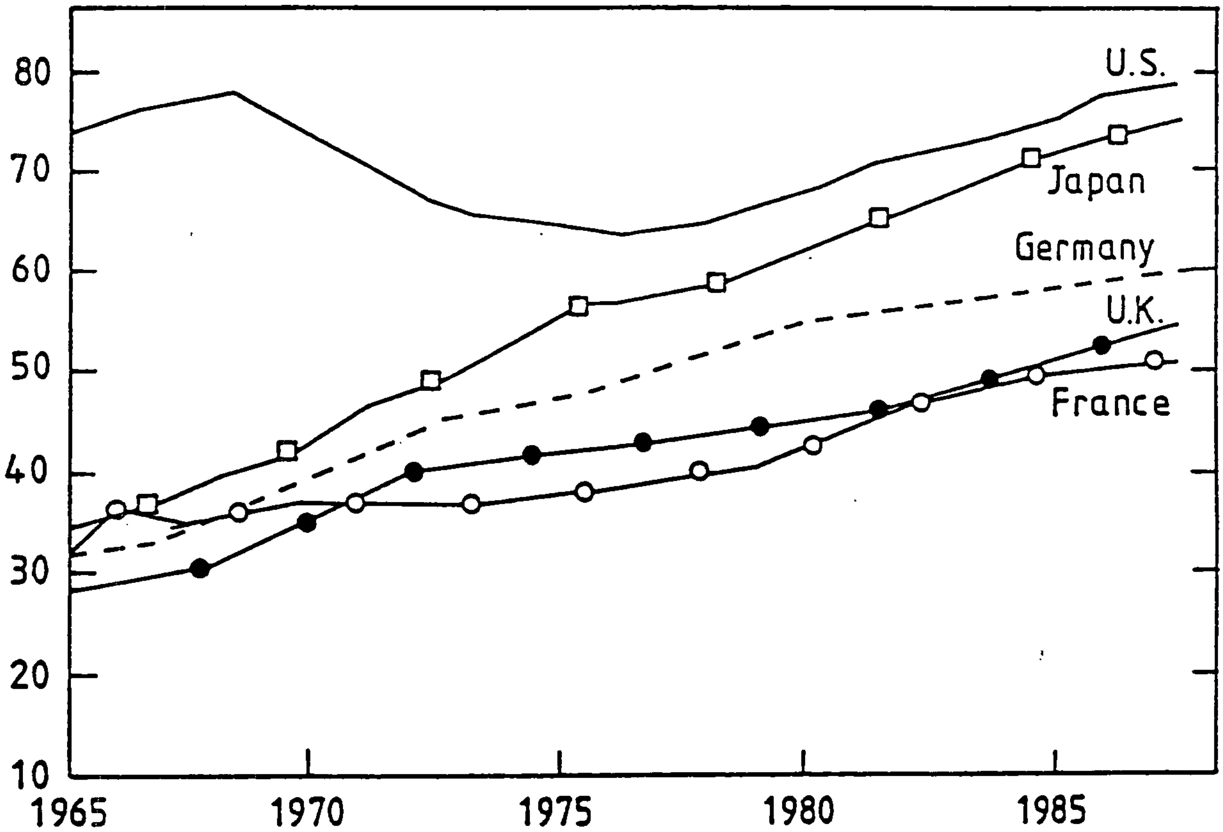
Industry Funding of R&D As Percent of Total R&D Funding, By Country, 1970-1987 (in percent)



Source: U.S. NSF data tapes, 1988.

Figure 2.4

Number of Scientists and Engineers Engaged in R&D Activities per 10,000 Labour Force Population, by Country, 1965-1987



Source: U.S. NSF data tapes, 1988.

Table 2.7

Scientists and Engineers Engaged in Research and Development for Selected Countries: 1965-1987 (Numbers in Thousands)

YEAR	FRANCE	GERMANY	JAPAN	UNITED KINGDOM	UNITED STATES
1965	42.8	61.0	117.0	49.9	494.6
1966	60.0	60.0	128.9	NA	521.1
1967	52.4	64.5	138.7	NA	534.4
1968	54.7	68.0	157.6	52.8	550.4
1969	57.2	74.9	157.1	NA	553.2
1970	58.5	82.5	172.0	NA	544.2
1971	60.1	90.2	194.3	NA	523.8
1972	61.2	96.0	198.1	76.7	515.3
1973	62.7	101.0	226.6	NA	514.8
1974	64.1	102.5	238.2	NA	520.8
1975	65.3	103.7	255.2	80.5	527.7
1976	67.0	104.5	260.2	NA	535.6
1977	68.0	111.0	272.0	NA	561.0
1978	70.9	NA	273.1	87.7	587.0
1979	72.9	122.0	281.9	NA	614.8
1980	74.9	NA	302.6	NA	651.7
1981	85.5	127.4	317.5	95.7	683.7
1982	90.1	129.0	329.7	NA	702.8
1983	92.7	133.1	342.7	94.1	722.9
1984	98.2	135.0	370.0	92.3	750.7
1985	99.0	136.0	381.3	90.0	790.0
1986	99.6	136.0	406.0	NA	825.0
1987	100.2	NA	411.0	NA	837.0

Note: Table includes all scientists and engineers engaged in research and development on a full-time basis except Japan, whose data include persons primarily employed in research and development, and the U.K. whose data include only the Government and industry sectors. The figures for FRG increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977. The figures for France increased in 1981 in part due to a re-evaluation of university research efforts. The 1985 figure for the U.K. is an estimate by the National Science Foundation.

Sources: NSF, Organisation for Economic Co-operation and Development, 1988.

Table 2.8 presents supporting information on the personnel engaged in R&D activities for the selected countries during the 1965 to 1987 period, that of scientists and engineers engaged in R&D activities per 10,000 labour force population.

As the information presented shows, the intensity of scientists and engineers in the labour force is relatively large in the U.S. and Japan. France and Germany employ about three-fourths the number of scientists and engineers in their labour force as compared to the U.S. and Japan. In the case of the U.K., the proportion of scientists and engineers employed in the labour force is about one-half that of the U.S. and Japan.

2.2.3 License Fees and Payments

Information on license fees and payments provides for a comparison of the relative advancement of technologies in a nation. That is, a nation with advanced technologies will, most likely, receive larger license fee payments from other nations, as compared to a country with limited technologies. Trends in license and fee payments over time serve also as an indicator of the technological advances over time. Conclusions from license and fee payment information must be drawn with caution.(3)

Table 2.8

Scientists and Engineers Engaged in R&D per 10,000
Labour Force Population for Selected Countries, 1965-87

YEAR	FRANCE	GERMANY	JAPAN	UNITED KINGDOM	UNITED STATES
1965	21.0	22.7	24.6	19.6	64.7
1966	29.2	22.4	26.4	NA	66.9
1967	25.3	24.9	27.8	NA	67.2
1968	26.4	26.2	31.1	20.8	68.0
1969	27.1	28.4	30.8	NA	66.7
1970	27.3	30.8	33.4	NA	64.1
1971	27.9	33.4	37.5	NA	60.7
1972	28.2	35.6	38.1	30.4	58.0
1973	28.5	37.1	42.5	NA	56.4
1974	28.9	37.8	44.9	NA	55.6
1975	29.4	38.6	47.9	31.1	55.3
1976	29.9	39.2	48.4	NA	54.8
1977	30.0	41.8	49.9	NA	55.7
1978	31.0	NA	49.4	33.3	56.5
1979	31.6	45.3	50.4	NA	57.7
1980	32.4	NA	53.6	NA	60.0
1981	36.3	46.5	55.6	35.8	62.0
1982	37.9	47.0	57.1	NA	62.8
1983	39.1	48.4	58.1	35.1	63.8
1984	41.2	49.1	62.4	34.2	65.1
1985	42.0	NA	63.2	32.8	67.4
1986	42.0	NA	63.5	NA	69.0
1987	42.2	NA	64.5	NA	70.0

Note: Table includes all scientists and engineers engaged in research and development on a full-time basis except Japan, whose data include persons primarily employed in research and development, and the U.K. whose data include only the Government and industry sectors. The figures for FRG increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977. The figures for France increased in 1981 in part due to a re-evaluation of university research efforts. The 1984 figures for FRG and the U.K. are estimates by the National Science Foundation.

Sources: NSF, Organisation for Economic Co-operation and Development, 1988.

Table 2.9 identifies, for the five selected countries, receipts and payments of royalties and fees for selected years in the 1972 to 1987 period. It also presents ratios of receipts to payments. As the data show, there are some differences between the nations but essentially no change in the ratios over time during the last fifteen years.

The larger ratio for the U.S. suggests that it has developed scientific and technical knowledge which is desired by other nations, and is also willing to transfer this knowledge to other countries for a fee. In the case of Japan, Germany and France, the receipts to payments ratios are smaller.

2.2.4 Trends in Patents Granted by U.S. Patent Office

The U.S. Patent and Trademark Office issues patents to both U.S. and foreign inventors. Information on the application and grant of patents in the U.S. Patent Office is avilable by nationality of inventor, and provides additional information on the status of science and technology among nations.[4]

The very large market and sales potential in the U.S. mandates inventors to seek the protection of the U.S. patent

Table 2.9

Receipts and Payments of Royalties and Fees for Selected Countries, 1972 - 1987

YEAR	UNITED STATES	JAPAN	GERMANY	UNITED KINGDOM	FRANCE
	(Million constant 1972 dollars)				
Receipts:					
1972	2,566	181	205	380	242
1975	3,186	197	201	412	318
1980	3,709	380	222	406	389
1987	5,300	460	230	410	421
Payments:					
1972	294	745	443	380	368
1975	376	500	477	403	381
1980	427	571	457	355	465
1987	520	681	492	360	510
Ratios:					
1972	8.7	0.2	0.5	1.0	0.7
1975	8.5	0.4	0.4	1.0	0.8
1980	8.7	0.7	0.5	1.1	0.8
1987	10.2	0.7	0.5	1.1	0.8

1987 Figures are preliminary estimates.

SOURCE: U.S. Department of Commerce and Organization for Economic Cooperation and development, data, 1988.

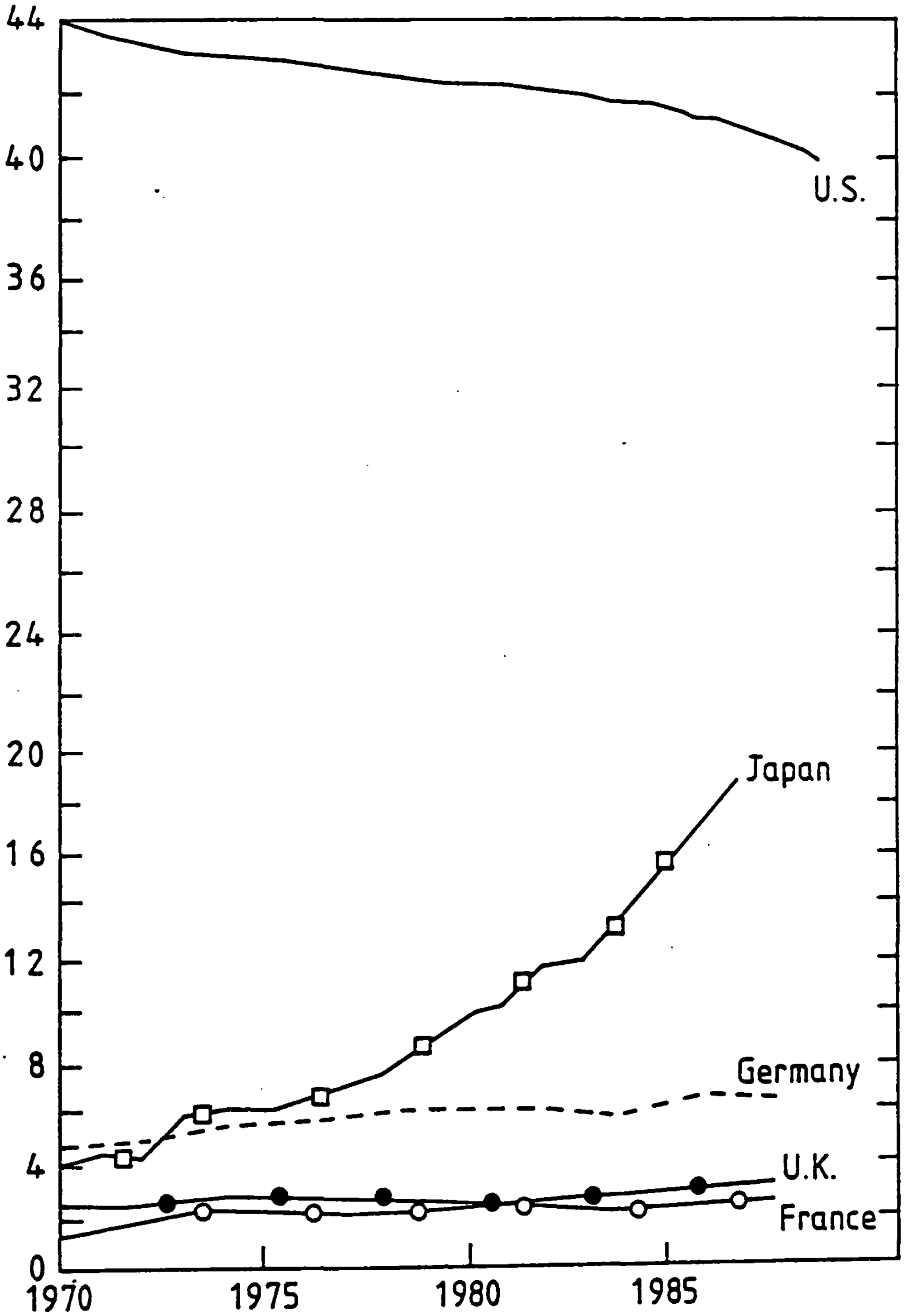
law by filing for a U.S. patent. Figure 2.6 and Table 2.10 provide information on patents granted by the U.S. Patent Office by nationality of foreign inventor.

Since 1975, Japan has been the largest foreign patenting country in terms of date of grant. Japanese inventors received 19 percent of all patents granted by the U.S. Patent and Trademark Office in 1987. The next largest foreign patenting nation was Germany, with 10 percent. France and the U.K. comprised slightly over two percent of all U.S. patents granted during the 1970 to 1987 period. Since 1980, Japanese patenting in the U.S. has increased by 85 percent and for Germany, by 18 percent. The patents granted to France and the U.K. have remained stable during the 1970 to 1987 period.

The Japanese share of patents increased in every area of technology. Increases of Japanese patents have been significant in internal combustion engines, from 17 percent to 44 percent, and in laser light sources and detectors, from 14 percent to 35 percent. Germany participation is seen in light-wave technology and in robots, although the total number of patents involved in small, while increased French activity is found in nuclear energy. Patents issued to the U.S. inventors show a secular decline during the 1970 to 1989 period.

Figure 2.5

Number of U.S. Patents Granted to
Inventors by Nationality, 1978-1987
(in thousands)



Source: U.S. Patent Office data tapes, 1988.

Table 2.10

U.S. Patents Granted to Inventors from Selected Countries by Date of Grant and Nationality of Inventor: 1970-87

YEAR	TOTAL	UNITED STATES	FRANCE	JAPAN	UNITED KINGDOM	GERMANY
1970	64,429	47,077	1,731	2,625	2,954	4,435
1971	78,317	55,984	2,214	4,029	3,464	5,522
1972	74,810	51,524	2,229	5,151	3,167	5,729
1973	74,143	51,504	2,143	4,939	2,855	5,587
1974	76,278	50,650	2,566	5,891	3,145	6,153
1975	72,002	46,715	2,367	6,352	3,043	6,036
1976	70,226	44,280	2,408	6,543	2,995	6,180
1977	65,269	41,485	2,108	6,217	2,654	5,537
1978	66,102	41,254	2,119	6,911	2,722	5,850
1979	48,854	30,079	1,604	5,251	1,910	4,527
1980	61,819	37,356	2,088	7,124	2,406	5,747
1981	65,771	39,223	2,181	8,388	2,475	6,252
1982	57,889	33,896	1,975	8,149	2,134	5,408
1983	56,860	32,871	1,895	8,793	1,931	5,423
1984	67,201	38,365	2,162	11,110	2,271	6,255
1985	71,661	39,554	2,400	12,746	2,495	6,665
1986	70,860	38,124	2,369	13,209	2,409	6,803
1987	72,000	39,000	2,100	13,500	2,500	6,900

Source: U.S. Patent and Trademark Office, 1988.

The decline in patenting by the U.S. from 1970 to 1987 occurred in many important technical areas, and may presage a shift in the economic condition of the corresponding industries. From 1970 to 1987, the share of U.S. patents granted to the U.S. dropped from 65 percent to 53 percent. Nearly all of this drop is due to the increase of Japanese-origin patents. The U.S. share dropped most in the following areas: aircraft and parts, motor vehicles and other transportation equipment, and office, computing, and accounting machines (including computers). These are all fields in which Japanese patenting increased markedly.

Furthermore, an analysis of thse patent applications suggests that Japanese patents are of very high quality and of some importance in scientific advances.

2.2.5 Summary

Information that indicates the science and technology activities in each of the five countries, shows surprising similarity in the resources allocated for such activities, when adjustments for the size of economy (GNP) are made. For example, the ratio of non-defence research and development expenditures to GNP in 1988 cluster around 2 percent more for all five countries, with Japan having the highest ratio of 2.8 and the U.K. the lowest of 1.5. A measure that identifies the intensity of scientific and technological personnel utilization (R&D scientists and engineers per

10,000 labour force) indicates similarity amoung the five nations.

On the basis of these two important science and technology measures, there is no reason to suggest a superior performance in scientific and technological activities on the part of Japan, and relative stagnation in these activities by the U.K., France, and FRG.

Certainly the closeness of these and other measures for the U.S. and Japan indicates no reason to identify Japan as the leader in a technological race with the U.S. Furthermore, the historical data on the science and technology activities over the last two decades clearly show that the science and technology activity trends have been increasing at a very modest rate for all five nations. Even more important, the relative differences in the science and technology activities for all five countries have remained very stable over the last two decades. The very rapid growth of Japan's advanced technology sectors, accompanied by Japanese success in overtaking the U.S. in world markets for advanced technology, cannot be observed from these science and technology indicators. Clearly there are severe national differences. For example, Japan has the highest ratio of non-defence research and development expenditure when compared to GNP, 2.8 percent, as compared to the U.S. ratio of 1.9 percent. Likewise, in Japan, the portion of research and development expenditures financed by the private sector, 70 percent, is higher than that for the four other nations, but these differences are not large.(5)

There are considerable differences in the number of patents granted, but these differences alone do not allow us to identify Japan as the leader in science and technology activities. While the number of patents granted to the Japanese have been increasing, and patents granted to the U.S. have decreased, the U.S. is the nation with by far the largest number of patents granted. In the year 1987, a total of 39,000 patents were granted to the U.S., as compared to only 13,500 granted to Japan. The historical information shows an increase in the patents granted to the Japanese over the last two decades (in 1970 the U.S. received 47,077 patents as compared to 2,625 granted to Japan) but the continuing dominance of the U.S. over Japan is obvious.

The number of patents granted to France and the U.K. is much smaller (approximatley 2,500 each) but has remained relatively stable in the 1970 to 1987 period. In the case of Germany, the number of patents granted has increased slightly over the same period, from about 4,400 in 1970 to about 7,000 in 1987.

In summary, the statistics on the scientific and technological activities in each of the five countries indicate relatively stable trends over time, and to a certain extent, similarity in the intensity of these activities, when adjustments for the magnitude of economy are made. This information does not identify significant increases in Japanese science and technology activities as the reason for the relatively sudden emergence of Japan as a leader in advanced technology industries, nor does this information provide evidence for the relative decline of the advanced technology sectors in the U.S., France, the U.K., and Germany.

FOOTNOTES TO CHAPTER II

1. The differences among the five selected nations in the emphasis of R&D expenditure by area, and the very small allocations of R&D funds to defence by Japan and Germany can be seen from the following table, which allocates government supported R&D in percentages by government ministries, departments and agencies.

COUNTRY	AGENCIES	PERCENT
United States	Department of Defence	53
	National Aeronautics & Space Admin.	15
	Energy	12
	Health and Welfare	10
	National Science Foundation	3
		93
	All Other	7
Japan	Prime Minister	57
	Ministry for International Trade & Industry	17
	Agriculture	9
	Education	8
	Health	4
		95
	All Other	5
Germany	Research and Technology	56
	Defence	17
	Industry	11
	Education and Science	8
	Agriculture	2
		94
	All Other	6

France	Defence	38
	Industry	26
	Universities	15
	National Centre for Telecommunication Studies	4
	Agriculture	3
		86
	All Other	14
United Kingdom	Defence	58
	Education and Science	14
	Industry	10
	Energy	8
	Agriculture	4
		94
	All Other	6

2. There is a remarkable similarity in the allocation of funds to R&D by the private sector among nations. The tabulation below shows R&D funding as a percentage of total sales for the ten largest companies in the U.S. and Japan for 1985.

RANK	FIRM	R&D RATIO TO TOTAL SALES (Percent)
UNITED STATES		
1	General Motors	2.9
2	Ford Motors	3.9
3	IBM	5.9
4	AT&T/Bell Systems	2.2
5	General Electric	2.9
6	United Technologies	6.0
7	Boeing	6.5
8	Eastman Kodak	5.7
9	IT&T	2.5
10	DuPont	3.3

JAPAN

1	Toyota Motors	3.7
2	Hitachi	5.8
3	Nissan Motor	3.3
4	Toshiba	4.8
5	Matsushita Electrical Ind.	2.9
6	Nippon Electric	6.0
6	Mitsubishi Electric	4.0
8	Mitsubishi Heavy Ind.	2.8
9	Honda Motor	3.6
10	Sony	7.0

3. The validity of such information on an international level has been debated for some time. The OECD (1984), for example, states the following regarding data on licensee fees and payments, referred to by the OECD as "Technological Balance of Payments" (TBP):

> Receipts and payments concern operations such as the transfer of patents, licensing agreements, provision of know-how, technical assistance, etc.
>
> The two main problems as regards the recording of flows are: heterogenous contents and non-comparability at international level.
>
> TBPs have a heterogenous content in that they record, side by side, not only flows relating to the transfer of technology proper (patents, manufacturing licences, know-how), but also in some countries services of a technical nature (assistance, training, consultancy work) and, in other countries, sometimes even factors related to industrial and intellectual property with no direct relationship to technology (trademark licences, film rights, management services, etc.).
>
> The non-comparability at international level stems not only from the differences in coverage noted above, but also from variations in the survey procedures (direct/indirect with regard to enterprises, exhaustive or on a sample basis) and in the way the information is

presented (broken down by type of firm, by activities, etc.).

Problems of interpretation are raised not only by the mixed contents of the TBPs, but also by the elusive character of certain international flows of technological knowledge, i.e. those for which there is no visible form of payment (among others: cross-licensing, transfer of knowledge to a subsidiary, international co-operation of a non-commercial type). Another such factor is the behaviour of the firms mainly responsible for transferring technology: i.e. multinational enterprises, for whom the type of payments registered in the TBP may be only one of several possible channels of reimbursement for technology transferred to subsidiaries. Their choice between these channels will be affected by fiscal and other considerations which may lead to the TBP data seriously overestimating or underestimating the real flows of technology involved. This means it is difficult to make an economic interpretation of intra-firm flows on the basis of accounts which, in the last analysis, are based on the firms' worldwide stragety.

4. A number of authorities question the validity of patent information as a measure of technology status in a nation. The OECD (1984), for example, states the following:

Patents are a science and technology output indicator but, owing to their specific characteristics, cannot be regarded as accurate measures of the numbers of inventions. Data on patents can, nevertheless, be used to assess the situations of the various economies as producers and users of technology. Moreover, the existence of international patent systems . . . and of foreign or external applications within national systems means that series are available which can give some indication of how the various economies fare in international dissemination of technology.

5. The relatively high Japanese non-defence research and development expenditures as a proportion of the GNP is the result of the almost complete absence of defence-related activities in Japan.

CHAPTER 3:

ECONOMIC THEORY AS A BASIS FOR GOVERNMENT SCIENCE AND TECHNOLOGY POLICIES

3.1 INTRODUCTION

It has been argued in the past by most, if not all, economists who subscribe to the classical economic theory, that the optimum welfare for society will be achieved with the least intervention via government policies in market economies. To be more specific, classical economic theory predicts optimum welfare for a nation, subject to the endowments available to that nation, assuming no government intervention takes place.

The internatiornal trade theory of classical economics stipulates further, the existence of comparative advantages for goods and services will result in orderly international trade among nations that will provide additional benefits to these nations, assuming that the government does not interfere in free international trade functions.

International trade theory has been of particular interest to economists, because of the importance of trade in the economic growth of a nation, or as stated by Alfred Marshall "the causes which determine the economic progress of nations belong to the study of international trade" (Marshall, 1930).

The following section (3.2) of this chapter therefore contains a critical review of the literature on classical international trade theory. The presentation is chronological, commencing with David Ricardo and John Stuart Mill, followed by a discussion of the contribution of Alfred Marshall and several others, and culminating with the international trade theory advanced by Heckscher and Ohlin and their colleagues.

Section 3.3 presents information on the recent international trade trends, particularly on the international trade in advanced technology products and contrasts the actual international trade performances of the five countries analyzed here with the prescriptions of classical economic theory regarding government policies for economic growth and development. To be specific, whereas classical economic theory predicts that government intervention in free markets (domestic and international) of a country results in economic decline and the worsening of its international trade position, the statistical information presented in this section indicates the very opposite.

Japan, with singularly comprehensive government policies that interfere with both domestic and international markets, has significantly increased its production of advanced technology products and established Japan as a leader in international markets for such products. Germany, the U.S., the U.K., and (to a lesser degree) France, with much more limited intervention by their governments in free market functions, have experienced a relative decline in their domestic production of advanced technology products and have lost significant shares of the international markets.

The concluding section of this chapter (Section 3.4) presents an appraisal of economists' attempts to modify classical economic theory and develop a "new" theory in order to reconcile the conflict between the classical economic theory and actual economic performance.

3.2 DEVELOPMENT OF CLASSICAL INTERNATIONAL TRADE THEORY

One of the early scholars of international trade some time before international trade was established as a discipline, was Daniel Defoe who, in his 1728 volume, A Plan for the English Commerce, stated an early, but essentially correct, observation on the national comparative advantage and national specialization principles as follows:

> It is a kind of proverb attending the character of Englishmen that they are better to improve than to invent, better to advance upon the designs and plans which other people had laid down, than to form schemes and designs of their own . . . The wool indeed was English, but the wit was all Flemish. . . we have turned the scale of trade, and send our goods to be sold in those very countries, from which we derived the knowledge and art of making them (Viner, 1937).

Some hundred years later, David Ricardo elaborated on Defoe's early observation and firmly established the theory of comparative advantage, as well as defining the concept of "opportunity cost" (Viner, 1937). Ricardo's comparative advantage theory (a theory which attempts to explain why one country has better opportunities to produce certain goods as compared to another) covered both natural resources as well as other factors. Ricardo explained the concept of comparative advantage for a country brought about by natural resources through the use of his well known example of Portugal and England; whereby Portugal has the natural resources to produce wine, whereas England has not. Conversly England has distinct advantages over Portugal in the manufacture of cloth. Ricardo, however, went further and stated the following:

> the capital of poorer nations will be naturally employed in those pursuits, wherein a great quantity of labour is supported . . . In rich countries, on the contrary, where food is dear, capital will naturally flow, when trade is free, into those occupations wherein the least quantity of labour is required . . . (Viner, 1937).

John Stuart Mill continued Ricardo's work and emphasized the role of relative labour costs among nations as one of the dominant components of comparative advantage.

Furthermore, the international spread of advanced technology product manufacturing facilities, in turn had the effect of educating labour forces in various countries (in John Stuart Mill's terminology). As early as 1848 he observed the impact of the learning curve:

> ... a people may be in a quiescent, indolent, uncultivated state, with all their tastes either fully satisfied or entirely undeveloped, and they may fail to put forth the whole of their productive energies for want of any sufficient object of desire. The opening of a foreign trade, by making them acquainted with new objects, or tempting them by the easier acquisition of things which they had not previously thought attainable, sometimes works a sort of industrial revolution in a country whose resources were previously undeveloped for want of energy and ambition in the people: inducing those who were satisfied with scanty comforts and little work, to work harder for the gratification of their new tastes, and even to save, and accumulate capital, for the still more complete satisfaction of those tastes (Viner, 1937).

It was Alfred Marshall, who in his The Pure Theory of Foreign Trade and Industry and Trade published in 1879 and 1919 respectively, added to the theory of international trade with a specific focus on the impact of technology on international trade. Marshall was the first economist to identify and describe the technology diffusion process across national boundaries and the first to relate technology diffusion to comparative advantage. Marshall's description of technology diffusion channels practised by Germany at the turn of this century, are essentially those in force in 1989 for most industrialized nations.

> In the early stages of modern manufacture scientific training was of relatively small importance. The Germans accordingly, recognising their own weakness in practical instinct and organising faculty, took the part of pupils, whose purpose it was to outrun their teachers. They began by the direct copying of English machinery and methods: (despite the British prohibition on the exportation of machines in effect at that time) and they next set themselves to get employment in English firms; and to offer steady, intelligent services in return for a low pay in money, and a silent instruc-

> tion in the inner workings of the business . . . And all the while Germany has been quick to grasp the practical significance of any master discovery that is made in other countries and to turn it to account (Marshall, 1930).

Marshall also uses examples of the U.K. adoptation of French technologies. He points out that the U.K.'s adoption of certain French technologies initially reduced exports of French goods to the U.K. and ultimately reversed the trade flow.

> . . . the Revocation of the Edict of Nantes in 1685 was a chief incident in a sustained policy of Contintental autocrats, which rid them of sturdy subjects. More than half a million of the ablest of them came to England, bringing with them that knowledge of technique, which was most needed by her just at that time. In particular the Huguenots taught her to make many light glass and metal wares, in which French genius excelled: and in a very short time such wares . . . were being sent to France and sold at a good profit (Marshall, 1930).

Marshall also points out the ability of the U.K. in the 18th Century to improve on the adopted technologies, and therefore to expand their international trade. This process was essentially identical to that undertaken by the Japanese on certain microelectronic products and machine tools adopted from the U.S. in the 1970's and 1980's. Marshall states:

> Another side of the same faculties is shown in such manufactures as those of the bicycle, motor car, submarine, and aeroplane: where French inventors had led, and a few French operative mechanics displayed a skill, a judgment and a resource which are nowhere surpassed. As these new delicate industries have reached the stage of massive production, the faculty of disciplined steadfast work becomes more important: the motor car, the submarine and the aeroplane tend to find

their chief homes in other countries, as the bicycle did long ago (Marshall, 1930).

A significant portion of Marshall's conclusion was also independently reached and reported by Jospeh A. Schumpeter in his initial German edition in 1912 (Schumpeter, 1934). Schumpeter's method was essentially that of an economic historian. Historical analyses applied to economic conditions over time in a particular country or industry were also undertaken by others. F.W. Taussig, for example, analyzed the German chemical industry sector over time and concluded that the advances in the industry and very significant increases in exports of chemical products from Germany in the pre-World War I period were due to the supply of an exceptionally educated and trained labour force in Germany, which in turn resulted from accessible technical education in Germany (Taussig, 1920).

Recently Hufbauer, in 1970, published a study which essentially supports Taussig in his conclusions on the importance of a highly skilled technical labour force and "other technology related factors" (i.e. investments, vintage of production facilities, R&D, etc.) in the growth and development of comparative advantage for a country in export commodities embodying advanced technologies (Haufbauer, 1970). Among the "other technology related factors", one of the most significant is the expenditures and activities in the area of research and development.

The general conclusion among economists working on the international trade and comparative advantage issues was that a nation, in order to achieve comparative advantage, would specialize in the manufacture of products which were either capital or labour intensive, depending on whether or not such a nation was endowed with a large supply of (cheap) labour or was rich in capital resources.

Some evidence contradictory to this hypothesis was presented by W.W. Leontief in 1956 in an analysis which showed that U.S. export industries are more skill-intensive, as compared to those U.S. industries which compete with imports from countries which have relatively less expensive labour (Leontief, 1956). To a certain extent, this surprising finding, referred to as "Leontiefs Paradox" in economic literature, was explained by the need to separate the labour factor inputs for the U.S. manufacturers into a pure labour portion and on "education" portion of labour which should be excluded from labour inputs.

3.2.1 Heckscher-Ohlin Contribution to Classical Economic Theory

The Heckscher-Ohlin theory of international trade represents the latest revision to the classical analysis of international markets in goods and services. The genesis of this theory is the analytical efforts undertaken by Heckscher and Ohlin during the early 1920's in Sweden (Heckscher, 1919; Ohlin, 1967). The initial definitive formulation of the Heckscher-Ohlin theory appeared in 1933 (Ohlin, 1967). A number of economists contribued to the development of specific issues related to the Heckscher-Ohlin formulation (Paul Samuelson, 1949).

During the last three decades a number of modifications and explanations of the Heckscher-Ohlin theory have been published, all of which remain in the classical framework. These include the models by Robinson (1956), Lancaster (1957), Johnson (1957) and others.

A large number of these modifications were attempts to interpret the Heckscher-Ohlin theory as a model that explains international trade in terms of different factor endowments in different countries (Haberler, 1961).

According to Professor Ohlin (1967) the Heckscher-Ohlin Model may be summarized as follows:

> . . . it is based on the assumption that ceteris paribus each country has an advantage in the production of commodities into which enter a relatively large quantity of factors that are relatively cheap in that country. It is the difference in the relative scarcity of the factors of production, and the fact that they are used in different proportions in the production of different commodities, which leads to an international division of labor and trade under the simple assumptions made. Commodities containing a large proportion of cheap factors are exported. No assumptions are made that the number of commodities is small or that all factors exist in all countries, where two or more are taken into account.

The influence of trade will be to increase demand in all countries for factors which are relatively cheap in that country. But, there are exceptions to this conclusion -- particularly under conditions of substitution of different factors for one another in cases of radical technological inequalities.

The influence of (1) trade on factor prices and (2) the influence of factor movements on trade makes it obvious that international commodity and factor movements can act as substitutes for one another. Reduced exchange of commodities will under many circumstances lead to factor price discrepancies which will increase factor movements. Reduction of factor movements will in many cases increase trade.

It is important to distinguish three types of capital intensity:

(1) The quantity of capital per individual working place used in the activity under consideration.

(2) The quantity of capital per worker.

(3) The percentage share of 'the total unit production costs' which consists of capital costs, in other words, the interest and depreciation costs. Other costs are chiefly labour costs.

Clearly as postulated by Ohlin, the Heckscher-Ohlin model "allows" for some, very limited, intrusion of government policy in the conduct of international trade and in establishing or maintaining comparative advantage in any country. However, the Heckscher-Ohlin theory barely allows for such policies, and certainly does not advocate an active role for governments.

3.2.2 Technology Issues in International Trade

Technology in its purest definition is a form of capital and therefore its availability in any nation is alterable by investment (Johnson, 1955). Any analysis of technology in the context of international trade must therefore consider it in terms of the costs and returns from such an investment. The first significant analysis of the role of technology in international trade was produced by J.R. Hicks (1953) and was concerned with balance-of-payments issues resulting from the technological advancement in the U.S. As the result of Hicks' analysis, intensive research was begun in the mid-1950's on the impact of technological change in international trade.

> That work, however, left largely unanalysed both the possibility that differences in real (absolute) factor prices resulting from technological differences would promote the diffusion of technology among countries, with consequent changes in comparative advantage and trade patterns, and the possibility that the same influences would promote the international migration of factors of production, with effects on the distribution of factors of production and of economic activity among countries (political units) and/or among geographical regions (climatic units). The first possibility, technological diffusion, has since been pursued along lines pioneered by Posner and especially by Vernon (Vernon, 1970).

Johnson, (1955) on the basis of Hicks analyses, assumed that:

> Technology, and differences in technological level among countries, will generate international trade at both the partial equilibrium or extreme microequilibrium level... of particular products in which a particular country or group of countries has established technological leader-

> ship (possibly reinforced by 'economies of scale'), and at the microeconomic level of comparative advantage based on superior technological level, superior 'endowment' (or past accumulation) of capital, or a combination of them. The fact that what is involved in the explanation of the trade in question is a combination of capital (both material and human) and technology is responsible for an analytical complexity that has frequently bedevilled policy discussions.

The existence of different technology levels among countries leads to what Haberler (1936) calls a "technology gap trade". The duration of such trade is, however, relatively short among industrialized nations (and decreases over time) as more mechanisms become available for technology transfer across national boundaries.

From the point of view of imports, rather than exports, several studies suggest that technology levels in a nation will relate directly to the level of imports; lower levels of technology will result in higher levels of imports and vice-versa (Kohli, 1983).

An examination of the U.S.' experience in this regard by Leamer and Bowen (1981) and Sveikauskas (1981) supports this conclusion. However, it is of some importance to recognize that the term "technology" may have different meanings and different connotations (Gruber et al., 1980; Griliches, 1984; and Balassa, 1979). In this regard Sveikauskas' (1983) recent conclusions are illustrative:

> A thorough examination of U.S. trade using the recently developed Leamer (1980) methodology comes to two primary conclusions. First, it is basically science and technology, and not occupational skills or capital intensity, which differentiates the U.S. economy from the rest of the world. Secondly, scientific personnel engaged in research or innovation are generally more abundant than their counterparts engaged in production. The United States differs most from other nations in two specific elements in the process of scientific and tehnical innovation: research and development and the presence of radical major innovations.
>
> These results provide substantial support for the notion that science and technology, rather than more general forms of capital formation and human skills, are fundamental within the broader area of science and technology. Such evidence suggests that future studies of world growth and development, and of world international trade, would do well to include fuller and more systematic treatment of science and technology in general and research and innovation in particular.

One of the reasons, which has been frequently advocated, for the importance of "pure science" as compared to "applied science", or engineering in creating and maintaining comparative advantage, is the rapid diffusion of applied science across national boundaries. Mansfield (1985) summarizes a recent research report on the rate of international diffusion of technology as follows:

> . . . the above findings seem to have at least three major implications. First, they help to explain why industrial innovations so often are imitated relatively soon after first introduction. Mansfield, Schwartz, and Wagner [1981] found that about 60 percent of the patented innovations in their sample were imitated within four years. Given that development decisions and new technology leak out so quickly (and that it is so often possible to invent around patents), it is easy to understand why this was the case. Moreover, these results provide new insights into the problems involved in providing proper incentives for innovation in a free-enterprise economy.
>
> Second, the results suggest that differences in the rate of diffusion of technological information do not

> play a major role in explaining interindustry differences in the ease with which innovations can be imitated. The interindustry differences . . . seem too small to be of major importance in this regard.
>
> Third, turning to issues of public policy, the results help to indicate the magnitude of the difficulties faced by recent (and not so recent) attempts by the US government to prevent the outflow to other countries of new American technology.

3.2.3 Summary of the Classical International Trade Theory

As initially postulated by David Ricardo, economic location determinants consisted of certain natural factors dictated by geography, e.g. climate, soil, proximity to markets, terrain, etc. which provided a certain comparative advantage to one location, region, or country over another.

The advancement of human knowledge and the rise in importance of manmade factors (i.e. technology, capital investment in production facilities, etc.) has gradually supplemented and/or displaced these natural determinants of economic activities.

The underlying explanations for the pattern of trade in economic literature are inseparable from the ultimate justification for trade itself. The question "Why do nations trade?" is almost invariably followed by the question "Why do certain nations trade certain commodities?".

The concept of comparative advantage in classical international trade theory states in general terms that in a world of competitive markets, trade will occur and will be beneficial whenever there are international differences in the relative prices of commodities (Hufbauer, 1970; Vernon, 1974).

Thus, differences in relative prices provide a strong incentive for trade. Each nation will export those commodities which are relatively less expensive at home and import commodities which are relatively more expensive. In doing so, each nation will expand production of the good for which it has a comparative advantage and divert resources away from the production of the more costly good for which it has a comparative advantage.

The basic premise of the theory of comparative advantage is that these adjustments are beneficial. Trade is a positive sum game in that for a nation to gain from trade there is no need for another nation to lose. Specialization results in an increase in world production and welfare, and world trade allows specialization. Trade will tend to grow until the gains from specialization are exhausted.

International trade will therefore be dictated by the free market mechanism. Any intervention in the free market by government policy is not only unwarranted, but also harmful.

Differences in relative prices provide the principal incentive for trade. The three principal reasons for these price differences, and therefore for the ability of a nation to export its goods and services at a lower relative price as compared to the prices of another nation, are as follows:

(a) international differences in the technology status and/or in the role of technology advancement;

(b) international differences in the prices of inputs in the production process and/or factors of production; and

(c) differences in demand for goods and services (including consumer tastes and preferences).

Classical trade theory stresses the second of the three reasons, i.e. the role of factor endowments (Crafts, 1984; Davidson, 1979). All else being equal, factors which are relatively more abundant should be relatively less expensive, and goods which employ these factors more intensively should also be relatively less expensive. Internationally, differences in factor endowments and differences in demand for the production of goods and services commodities could potentially lead to differences in the relative prices of commodities and form the basis of trade. This is the Heckscher-Ohlin model of international trade: a nation will export those commodities which use intensively its relatively abundant factors.

The Heckscher-Ohlin model remains a cornerstone of international trade theory.

In the early days of the development of the classical international trade model, the number of variables was few and each of these represented a "bundle" of goods and services. Land, labour and capital, for example, were the intial three factors. With the passage of time the international trade models were modified to accept a larger number of factors, including different types of capital (with different vintages of technology) and different categories of labour (such as scientific and technical personnel) and so forth. With so many factors and commodities, however, the extended classical international trade models lost some of their analytical capability. For example, international trade in the Heckscher-Ohlin model represents in reality an exchange of factor services. One country's relatively abundant supply of certain factors of production (i.e., capital and/or labour) may be made available to another country and/or the rest of the world through its trade in goods and services. However, the same combination of factors of production may be used to produce different commodities.

Also, if factors of production are mobile, the same results can be obtained through trade in these factors themselves. The complexities and the large number of variations of these variables do not allow a formal use of the Heckscher-Ohlin or other classical international trade models. In fact as reported by some economists, both types of trade exist side by side (Balassa, 1985;

Bowen, 1980). Some of the more mobile factors such as raw materials are traded on world markets, while other factors of production (such as skilled labour) may have a certain mobility across national boundaries (Davidson, 1979; Stern and Maskus, 1981; Bhagwati, 1983).

Advanced versions of the Hecksher-Ohlin model therefore explain some, but not all, patterns of international trade (Leamer, 1984). Certain important anomalies remain, however, especially those associated with international trade in advanced-technology goods.

Furthermore, classical trade theory ascribes the source of trade to differences in what economists call national characteristics, which prescribe relative abundance or scarcity of factors of production in a country that have significant geographic origins (Posner, 1961). The gains from trade arise from the easing of relative scarcities. Much of international trade, however, takes place between nations with similar national characteristics and consists of the simultaneous export and import of commodities which are close substitutes (Leamer, 1981). For many commodities and high technology products, similarity rather than difference appears to explain the pattern of trade. The fact that international trade takes place in very similar commodities is particularly damaging to the Heckscher-Ohlin model.

To be fair, some of the trade in similar commodities can be explained within the framework of the Heckscher-Ohlin model (Maskus, 1983). For other commodities, especially raw materials, transportation costs may account for a significant portion of the final cost because proximity to or access to inexpensive modes of transportation (such as ocean shipping) may allow a foreign producer to capture portions of the domestic market even though domestic producers enjoy a comparative advantage in production and export of these commodities to other markets (Lunn, 1983; Hollander, 1984).

There have been further developments of the Hecksher-Ohlin theory. Helpman and Krugman (1985) for example, expand the Hecksher-Ohlin formulation by admitting the existance of a sector of the economy in which there is monopolistic competition.

Clearly the Heckscher-Ohlin theory of international trade, and by extension, the classical theory of trade, provide only partial and not very satisfactory explanations of the international trade transactions as presented in the following section. The Heckscher-Ohlin theory does not appear relevant to the wide range of advanced technology products. To explain the prevalence of advanced technology products in international trade, one must look for other causes and reasons. So long as differences in prices are the <u>sole</u> basis for trade, there is no explanation as to why a nation would simultaneously export and import a wide range of advanced technology goods.

Most emphatically, the classical models of international trade prescribe non-intervention by governments in international trade as the optimum course of action. The classical theories clearly and explicitly argue that all government policies to assist the domestic industry sector will result in damage to that nation's economy. Brander (1984) comments on this further:

> The noninterventionist stance of trade theory is really a slight extension of one of the most important themes in economic thought, first articulated by Adam Smith (1776). This theme is that competition between private producers promotes the efficient use of resources. A precise statement of the theme is contained in a theorem known as the first theorem of welfare economics: "Perfect competition is efficient." In other words, private markets do about as well as could be hoped for in promoting efficiency, and intervention can only reduce efficiency. Furthermore the second theorem of welfare economics and the associated policy statements assert that any distributional objective can best be met by reallocating wealth or income and then just leaving private competitive markets to do their job of enforcing efficiency.

The fundamental assumptions used in classical international trade theory, with regard to government policies to foster domestic industries and increase exports, are summarized by Grossman and Richardson (1984):

> In a world of perfect markets and perfect competition, prices reflect the scarcity value of all goods and provide appropriate incentives for economic decision makers. Each consumer purchases units of goods until the value to him or her of the last of these is

> exactly equal to the price. Firms take product prices as data, being themselves too small in the overall market to influence them, and hire resources until the cost of producing the marginal unit is equal to the revenue that is realized by doing so. In this way the market equates marginal benefit in consumption with marginal cost of production.
>
> In this idealized world there is no reason for a government to prefer one industrial structure over another. All industries are equally "profitable," profit being the normal return to such scarce factors as managerial ability and entrepreneurship. "Strategy" (by which is meant actions that are taken to induce favorable responses by rivals) plays no role, since all actors perceive themselves as being too small to influence market outcomes and behave as if the market environment were a given.

As presented in the following section, these fundamental assumptions of classical economics recieve no support from the actual empirical information on international product flows. On the contrary, international trade statistics indicate that countries that significantly intervene in the free markets, such as Japan, are able to increase their domestic production and exports at a very significant rate. Conversely, some countries that practise nonintervention in market economies, as prescribed by classical economic theory, such as the United Kingdom or the United States, have performed relatively poorly in the domestic and international markets. The following section presents empirical information to support these assertions.

3.3 INTERNATIONAL TRADE FLOWS: RECENT EMPIRICAL EVIDENCE

3.3.1 Introduction

The industrial revolution began in the United Kingdom in the mid-19th century and rapidly spread to the other Western European nations and crossed the Atlantic (Crafts, 1984). It is important to underline that the rapid industrialization in the U.K., Germany, France and the U.S. resulted in very significant exports of goods and services of all kinds, but in particular of products which represented the most advanced technologies at that time[1] (Heckscher, 1919; Aldcroft and Richardsen, 1970; Kennedy, 1982).

For example, at the turn of this century, the U.K.'s manufacture of steam railroad locomotives had captured about 75 percent of the world's market for this advanced heavy engineering product. The U.K. also represented about 60 percent of the world's iron and steel exports, about 80 percent of international trade in textile machinery, and about 70 percent of the world's trade in metal working machinery (Kindlebergen, 1964; Habakkuk, 1962). Aromatic coal tar manufacturing processes developed in Germany (in particular by Farben A.G.) in 1900 had a virtual worldwide monopoly for commercial textile dyes (Tyszynski, 1951). After World War I, the U.K. dominated world trade in several advanced technology areas such as bulk manufacturers, inorganic chemicals, iron and steel, and metal working machinery. Germany, France and the U.S. also has substantial shares of world markets for these products (Kahn, 1946). The Western European nations together maintained their dominance in the world's markets for most industrial products. Further, Germany, France and the U.K. added new advanced product lines to their growing export trade. These included electric generation and distribution equipment (from Germany, France and the U.K.), household electrical goods and motor vehicles (from Germany, France and the U.K.), optical goods and photographic equipment (from Germany) and telephone and telegraph apparatus (from Germany and the U.K.).

U.K. accomplishments in science before World War II can be seen from the work of Tizard Consulting, which began the development of radar in the 1930's and successfully completed this device during World War II (Matthews, et al., 1982). U.S. industry experienced an equally rapid growth in size and in the manufacture of advanced product lines, but because of the very large domestic market, choose to contribute very little of its products to international trade (Fabricant, 1942). Among scientific accomplishments in the U.S., the development of methods for organic chemicals, synthetic alcohols and synthetic rubber manufacture, and the design of large scale electric systems, are of particular importance. Western European nations and the U.S. held a comparative advantage prior to World War II in most important industrial product lines (Table 3.1).

TABLE 3.1

Revealed Comparative Advantage in 1913 and 1937

UNITED KINGDOM	GERMANY	UNITED STATES
1913		
Rail and ship	Electricals	Non-ferrous metals
Textiles	Cameras/books	Agricultural Products
Iron and steel	Leather/wood	Industrial equipment
Spirits/tobacco	Industrial equipment	Automobiles
	Chemicals	Electricals
	Metal manufactures	Metal manufactures
	Finished goods	Leather/wood
	Iron and steel	Rail and ship
	Nonmetalliferous materials	Iron and steel
	Apparel	Cameras and books
1937		
Spirits/tobacco	Metal manufacture	Agricultural Products
Textiles	Finished goods	Cars and aircraft
Rail and ship	Chemicals	Industrial equipment
Finished goods	Cameras/books	Electricals
Electricals	Nonmetalliferrous materials	Iron and steel
	Rail and ship	Non-ferrous metals
	Electricals	Cameras/books
	Industrial equipment	

SOURCE: Crafts (1984) derived from Tyszynski (1951).

After World War II, because of the destruction of industry in Germany and France as well as other nations, U.S. exports of all kinds increased rapidly (Rostas, 1948). The research and development activities in the United States throughout this period resulted in a number of advanced products. These include open-hearth furnaces in steel making, polyesther resins in plastics, and semiconductors in microelectronics, etc.

The economic history of Japan represents a sharp contrast to that of Western European nations and the U.S. After several centuries of social, political and economic isolation, Japan with the advent of the Meji era in the 1840's, began its own industrialization process, but with very limited exports due to domestic demand. After World War II, the Japanese industrial base was severly damaged and Japanese exports were represented by cottage industry products. Throughout the 1960's and 1970's, the Japanese industrial base became more advanced and Japanese exports gradually changed from cottage industry goods to more advanced technological products.

By the mid-1970's, the Japanese were a major factor in the international trade of metalworking machinery, textile machinery, microelectronic products of all kinds, computers and telecommunication equipment, photographic and scientific goods and advanced product lines in other sectors. Throughout the period, Western

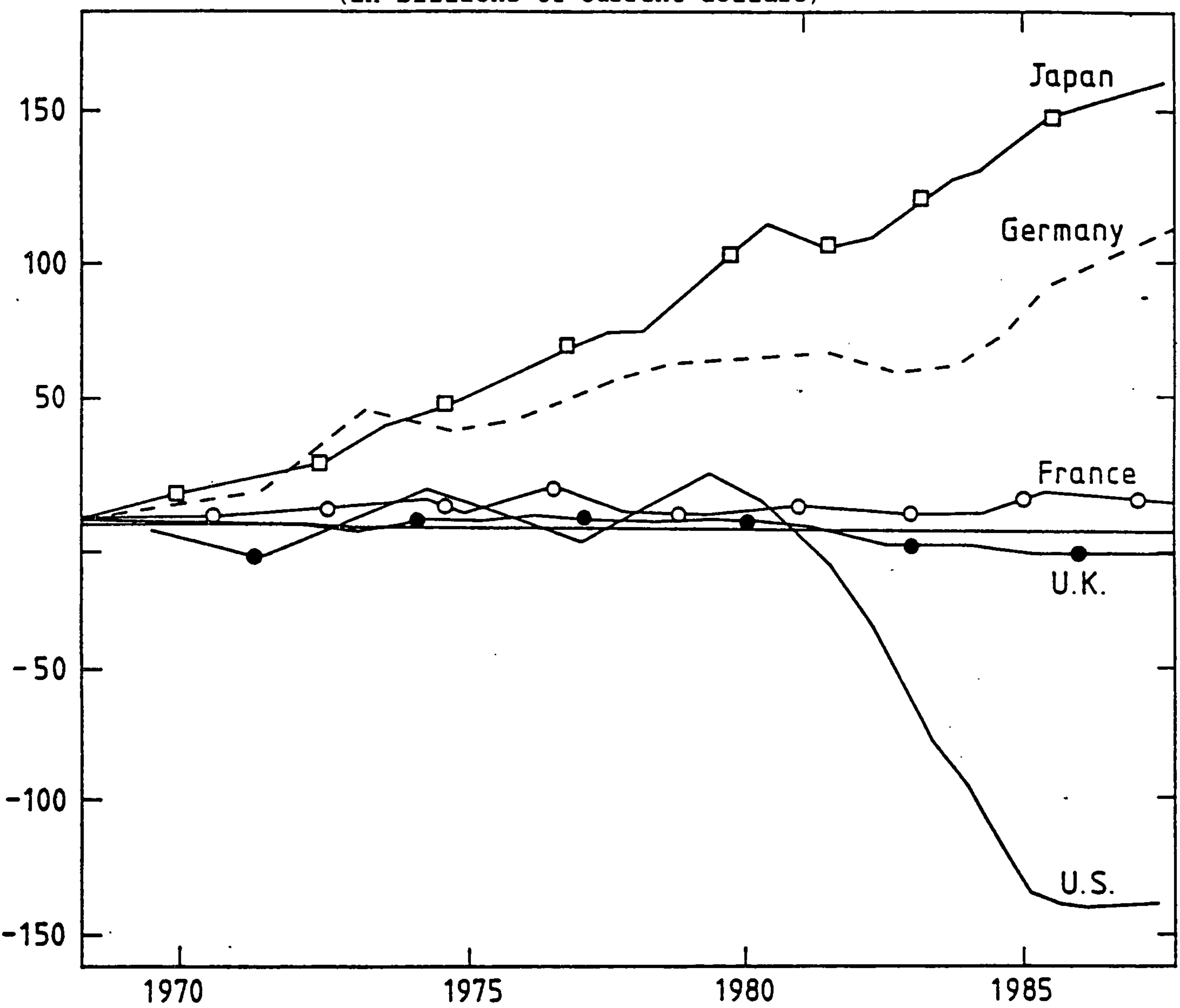
European nations and the U.S. experienced losses in their exports.

Figure 3.1 depicts these changes in the trade balance in manufacturing for the five countries during the 1970 to 1988 period. As can be seen, Japan has dramatically increased its trade balance in this period, followed by a large increase for Germany. The trade balance of the U.K. during the 1970 to 1988 period has remained essentially stable.

The trade balance of the U.S. shows the most dramatic change during the 1970 to 1988 period, a change in which the trade balance in manufacturing has declined from positive in 1980 to negative in 1987. Not only have the directions in trade balance in manufacturing changed during this period, but the magnitude of the trade balances for some nations has changed. In the case of Japan and the U.S., the trade balances in 1970 were essentially equal. Both nations exported goods valued at approximately the same level as their imports. By the year 1988, Japan's trade balance in manufacturing showed a surplus of over $150 billion, and the U.S. trade balance had declined to a negative $150 billion. Germany, starting also with an equal trade balance in 1970, had increased its trade balance to approximately $100 billion by 1988. The changes in the magnitude of the trade

Figure 3.1

Trade Balance in Manufacturing
Selected Countries, 1970 - 1988
(in billions of current dollars)



Source: U.S. DOC, ITA printouts, 1988.

balances during the same period for the U.K. and France were relatively minor.

It is of particular interest to trace the international trade position for these nations over time in products which have been produced through the use of advanced technologies or represent advanced technology products. The term "advanced technology" products as used here is that defined by the U.S. DOC and used by OECD member countries.(2) Advanced technology products according to this definition include: certain chemicals, man-made fibres, drugs, engines, electronic machinery, communications equipment, aircraft components and instruments.

Table 3.2 and Figure 3.2 traces comparative changes in the export shares of all advanced technology products for the 1955 to 1987 period.(3) Japan's performance has been by far the most impressive during this period. In 1955, Japan's exports of all manufactured products represented 4.8 percent of total exports by the OECD member countries. Japan's export share for advanced technology products was only 1.8 percent. By 1987, Japan had increased its shares in exports by factors of almost 4 and 8, to 17.6 percent and 16.2 percent respectively. Export shares of the United States in the same period were reduced by almost one-half from 25.9 percent and 35.0 percent in 1955 to 14.1 and 18.7 percent in 1987.

TABLE 3.2

Comparative Changes in World[1] Export Shares of all Manufactured Products and Advanced Technology Products from 1955 to 1987 (in percent)

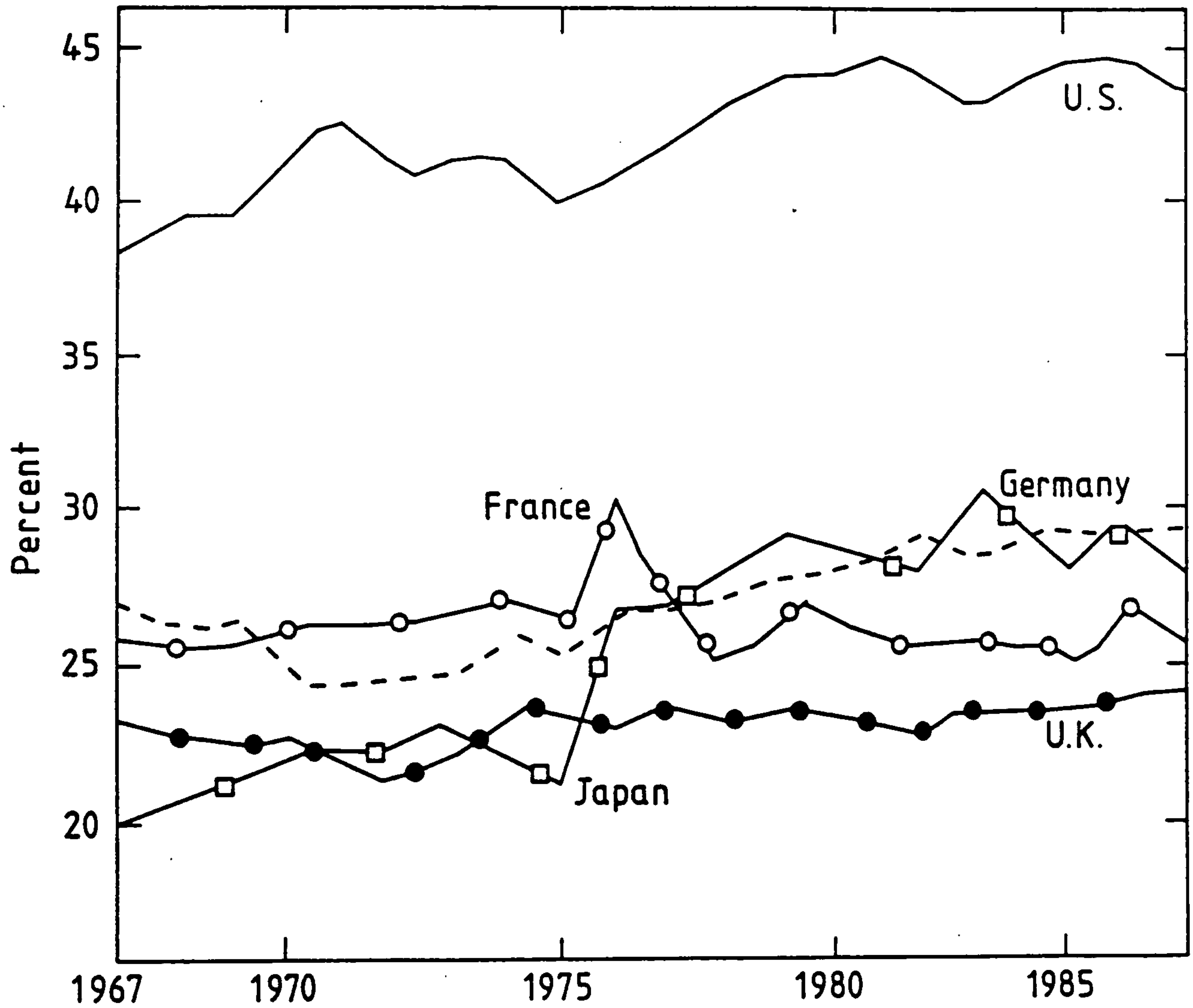
COUNTRY AND PRODUCT GROUP	1955	1960	1970	1980	1987
United States					
All manufactured products	25.9	22.8	18.4	16.4	14.1
Advanced technology products	35.5	27.6	23.1	19.9	18.7
Japan					
All manufactured products	4.8	6.5	8.9	11.0	17.6
Advanced technology products	1.8	4.2	9.7	14.5	16.2
Germany					
All manufactured products	14.6	18.2	19.8	19.8	18.3
Advanced technology products	17.6	21.2	20.4	19.3	24.3
France					
All manufactured products	8.8	9.1	8.3	10.2	10.7
Advanced technology products	6.4	7.7	7.6	9.0	8.6
United Kingdom					
All manufactured products	11.3	13.7	12.8	14.3	13.1
Advanced technology products	9.4	14.0	13.3	14.7	13.7

1 - "World" exports are defined as the sum of the exports from OECD member countries.

SOURCE: United Nations, OECD, National Institute of Economic and Social Research (London), and U.S. Department of Commerce, 1988.

Figure 3.2

Proportion of Total Exports Represented by Advanced Technology Products, Selected Countries, 1967 - 1988



Source: U.S. DOC, ITA Printouts, 1988.

Changes in the export shares for Germany, France and the U.K. showed a certain stability in this 22 year period, although Germany increased its share of advanced technology product exports from 17.6 percent in 1955 to 24.3 percent in 1987.

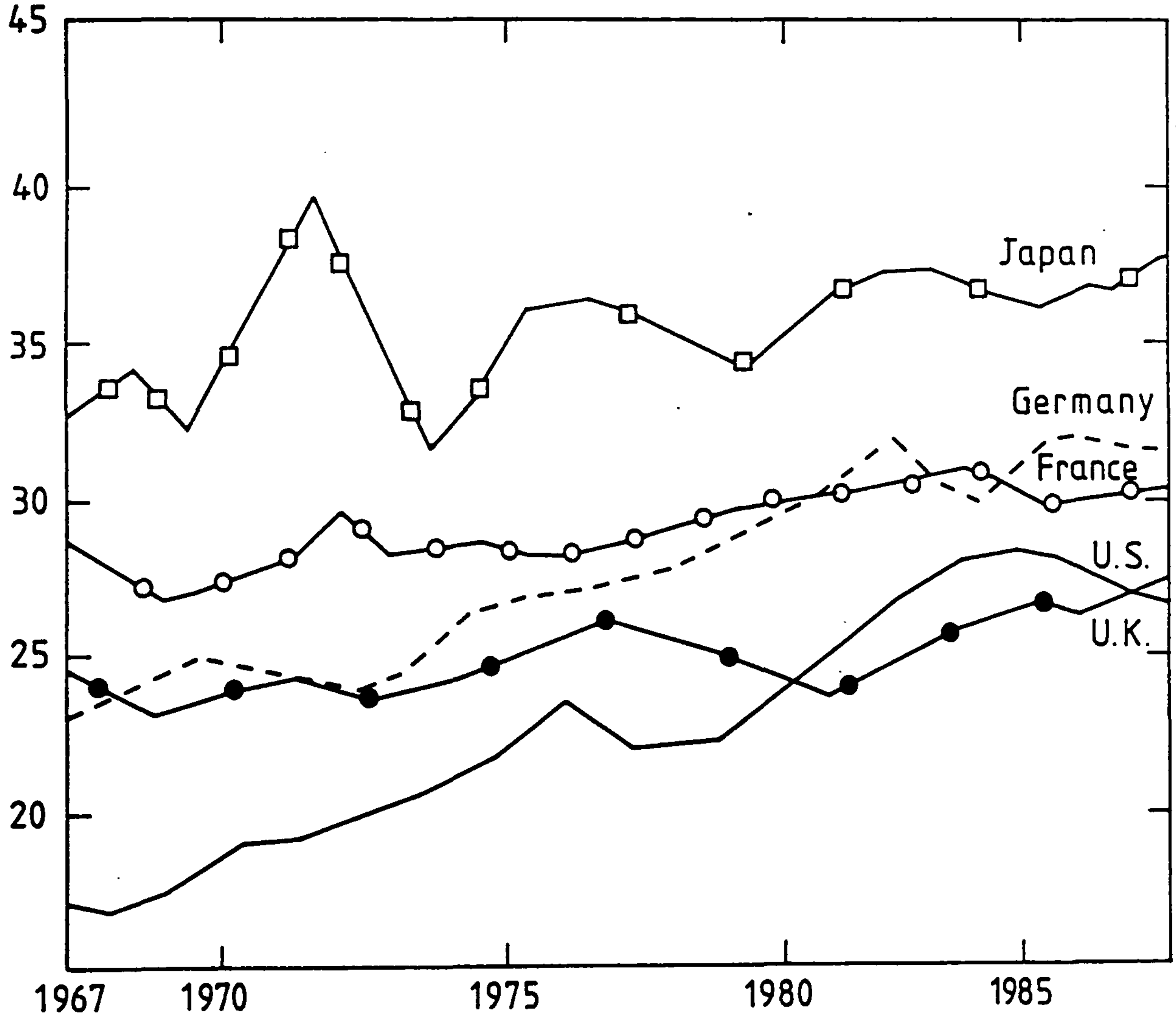
Figure 3.3 shows the proportions of imports, represented by advanced technology products, for the U.S., Germany, France, the U.K. and Japan for the 1967 to 1988 period. The information presented shows that all five nations have increased the proportionate value of advanced technology imports in their total imports. However, for Germany, the U.S. and Japan, imports of advanced technology products as a share of total imports have increased at a significant rate during the 1967 to 1988 period. In the case of Japan and Germany, the expansion of exports of advanced technology products coincides with increased imports of advanced technology products. This simultaneous trend of increasing exports and increasing imports of advanced technology products for a nation represents a commonplace occurrence in advanced technology trade.(3)

3.3.2 Recent Developments in United States International Trade

The U.S. has experienced a rapid decline in exports of all types of goods during the last decade, in particular in the export of the goods that embody advanced technologies. It has been argued in the academic community that this decline in U.S.

Figure 3.3

Proportion of Total Imports Represented by Advanced Technology Products, Selected Countries, 1967 - 1988



Source: U.S. DOC, ITA printouts, 1988.

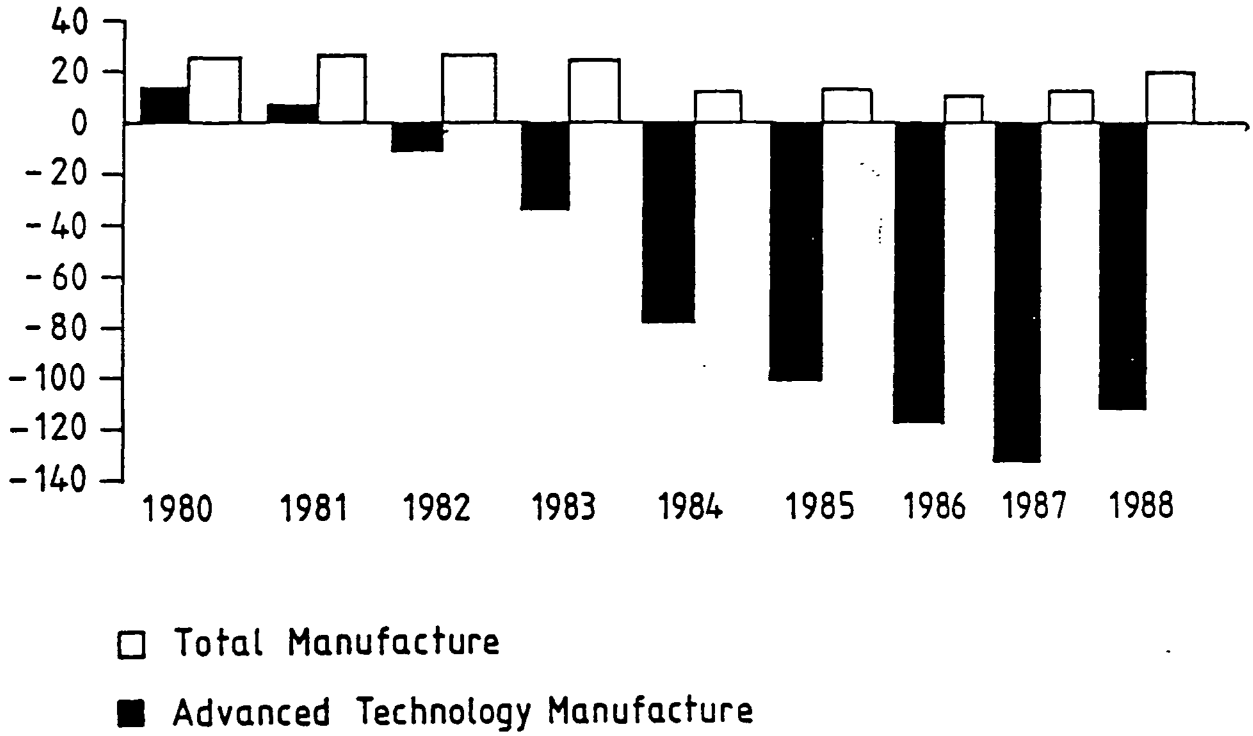
exports of advanced technology products, and therefore the loss of comparative advantage, is a direct result of a decline in scientific activity.[4]

This rapid decline in the U.S. balance of trade requires more detailed analysis. Historical data indicate that the manufacture component of U.S. merchandise trade has been positive during the last eight decades and has remained in the black throughout the mid 1980's.[5] In 1980, U.S. manufacturer's exports still exceeded imports by $14 billion; a year later in 1981, the surplus had shrunk to $6 billion. The U.S. merchandise trade turned to a deficit of $13 billion in 1982; followed by ever-growing deficits of $41 billion in 1983, $88 billion in 1984, $113 billion in 1985, and $138 billion in 1986. In 1987 the deficit was $143 billion, and in 1988 it was estimated at $125 billion, as shown in Figures 3.4 and 3.5.

The U.S. merchandise trade performance during the 1980 to 1987 period shows that U.S. exports to the world remained essentially stable, while total imports rose by over 42 percent (Figure 3.6). Large increases in imports over the 1980 to 1987 period were recorded for Japan and the NICs of Southeast Asia (South Korea, Taiwan, Hong Kong and Singapore) -- 119 and 123 percent respectively -- with most of the increase occurring since 1983.

Figure 3.4

Trade Balance in Total Manufacture
and Advanced Technology Manufacture
United States - 1980-1988
(in billions of current dollars)

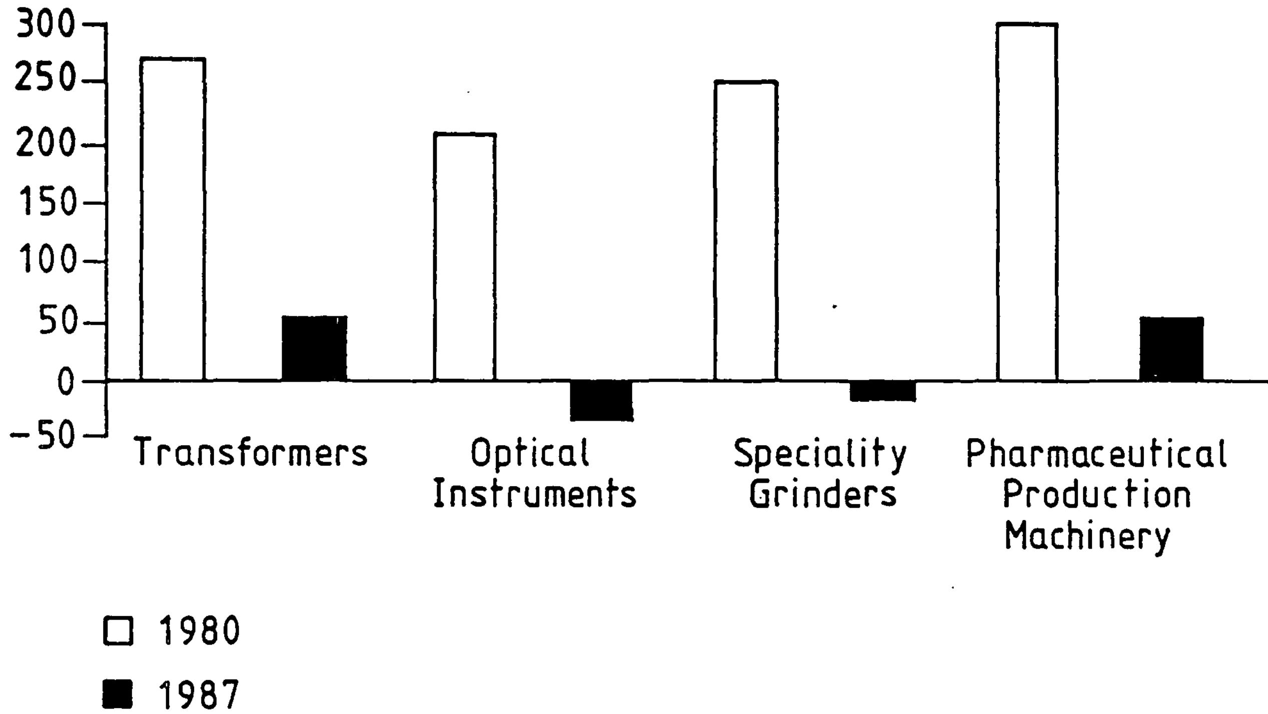


Source: U.S. DOC, ITA printouts, 1988.

Figure 3.5

Trade Balance in Selected
Advanced Technology Products,
United States, 1980 and 1987

(in millions of current dollars)

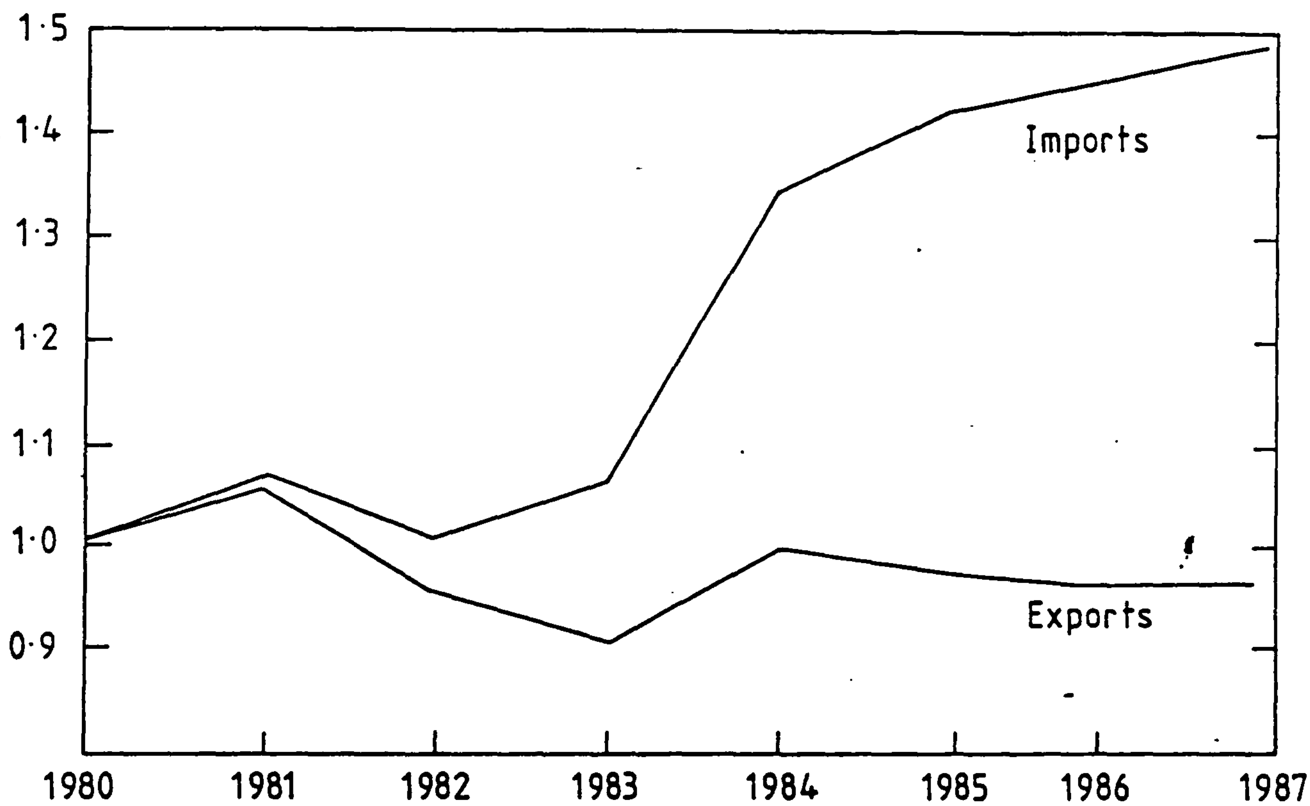


Source: U.S. DOC, ITA Printouts, 1988.

Figure 3.6

Merchandise Trade, United States,
1980 - 1987

(Index 1980 = 1.00)



Source: U.S. DOC, ITA Printouts, 1988.

U.S. manufactures exports increased slightly during the 1980 to 1988 period to all major recipient nations (Figure 3.7). Likewise exports of U.S. microelectronic products, the most advanced product group among advanced products, showed only marginal changes during the same period[6] (Figure 3.8).

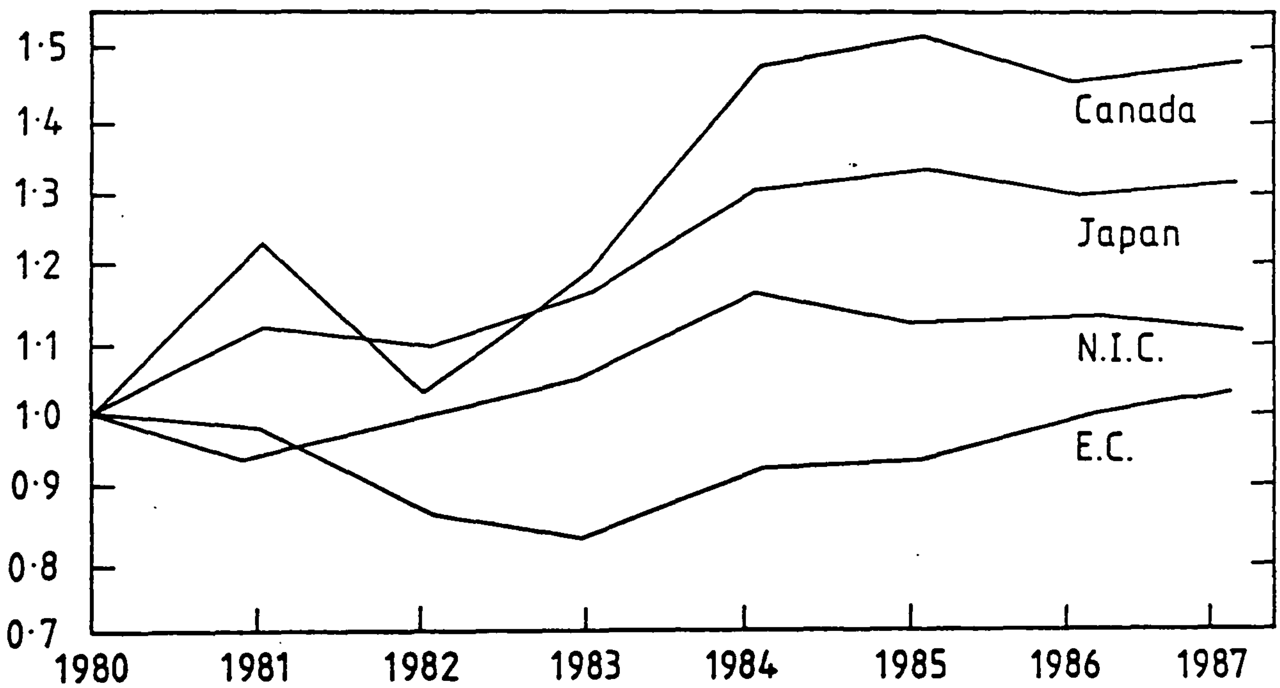
Manufactures imports during the 1980 to 1988 period increased at a rapid rate. Clearly, imports of manufactured goods were the principal reason for the overall growth in merchandise imports (Figure 3.9). The most significant increase on the import side was in trade with the so-called "Rest-of-World" group (ROW). Much of the growth in U.S. imports from the ROW countries, however, can be attributed to production of U.S. firms which are contracting for production and/or assembly in many of the ROW countries because of cheaper labour costs. In 1988 the estimated imports from ROW countries declined somewhat, most likely as the result of the weaker dollar in the international markets.

Figure 3.10 presents information on U.S. imports from selected countries for 1985 and 1987 to indicate the growth of these type of imports to the United States.

U.S. advanced technology exports during the 1980 to 1988 period increased by some 27 percent (Figure 3.11). U.S. advanced technology exports to Japan, starting in 1980 from a modest base, increased by over 30 percent, with the most rapid growth taking

Figure 3.7

Exports of Manufactures to
Selected Geographic Regions,
United States, 1980 - 1987
(Index 1980 = 1.00)



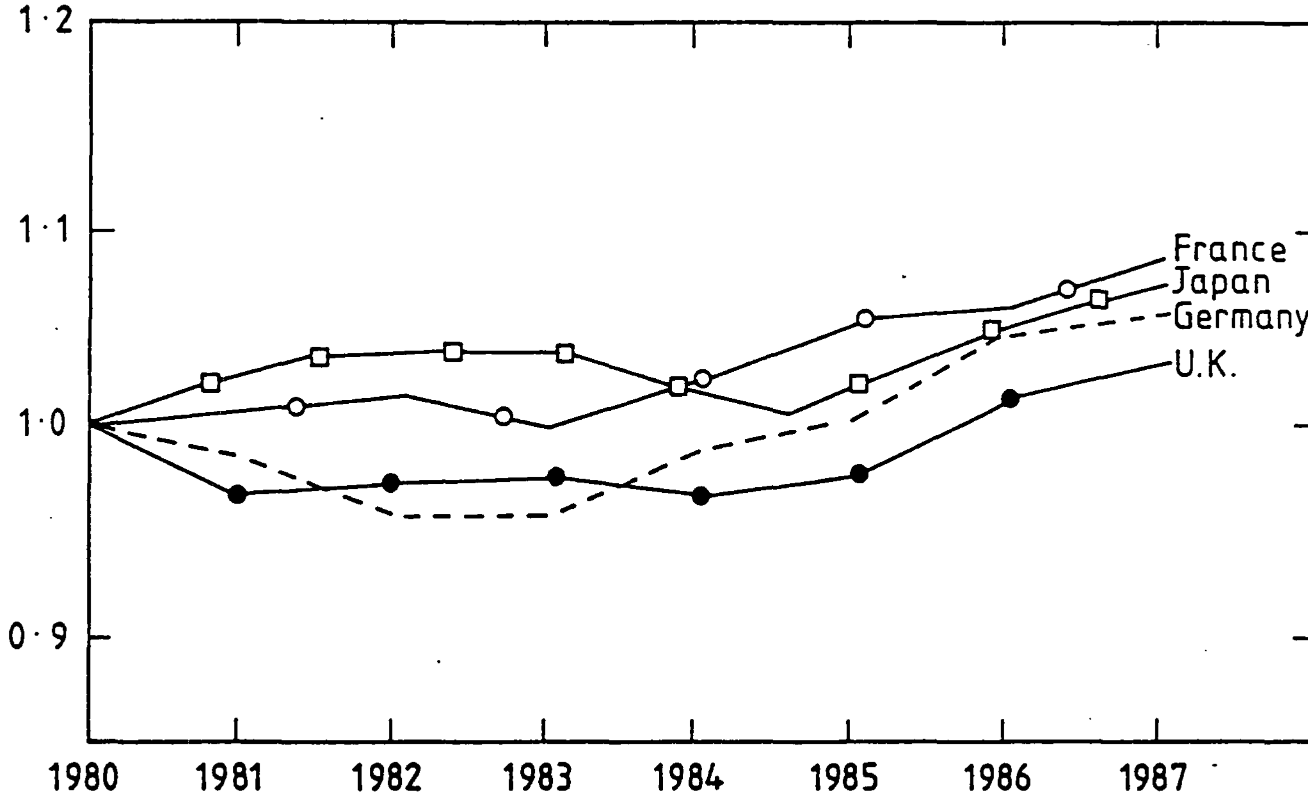
N.I.C. = Newly Industrialized Countries (Korea, Taiwan, Singapore, Hong Kong)

Source: U.S. DOC, ITA Printouts, 1988.

Figure 3.8

Exports of Advanced Microelectronic Products
to Selected Countries, United States
1980-1987

(Index 1980 = 1.00)

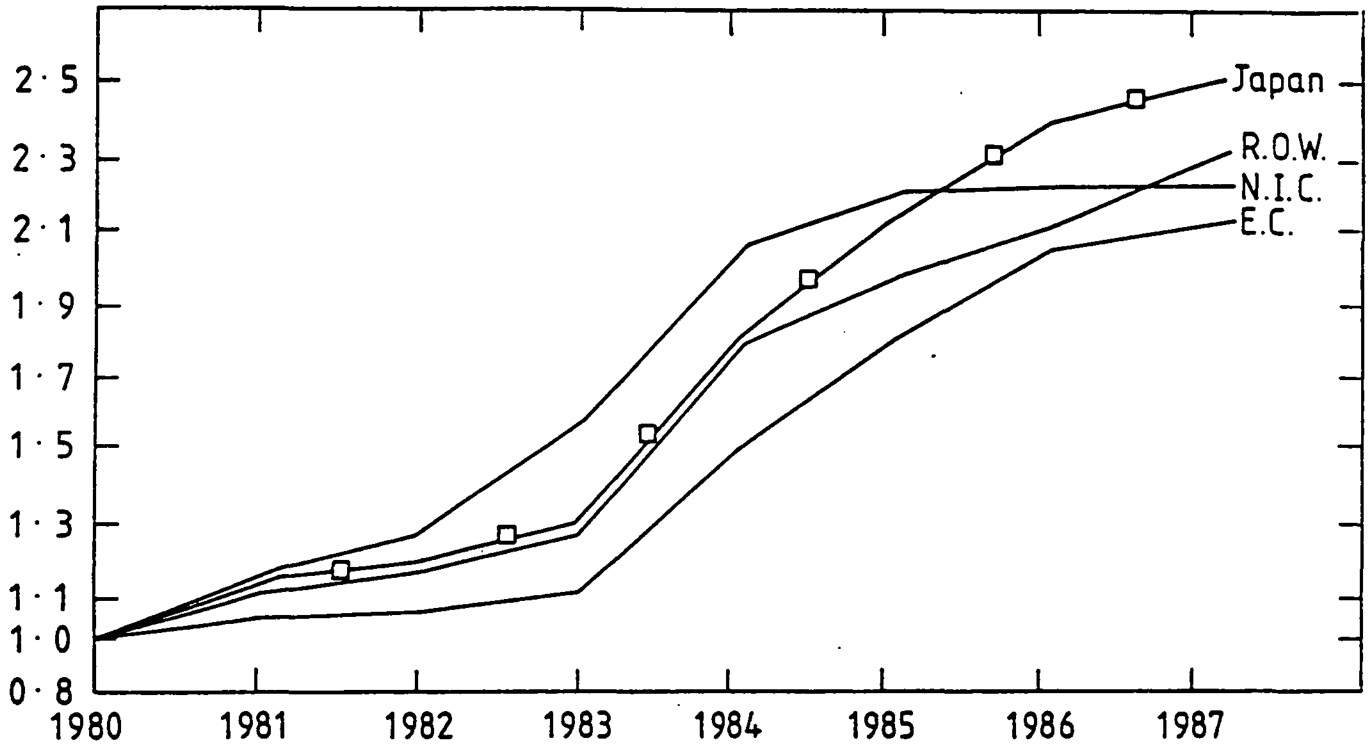


Source: U.S. DOC ITA printouts, 1988.

Figure 3.9

Manufacturers Imports from
Selected Geographic Regions,
United States, 1980 - 1987

(Index 1980 = 1.00)

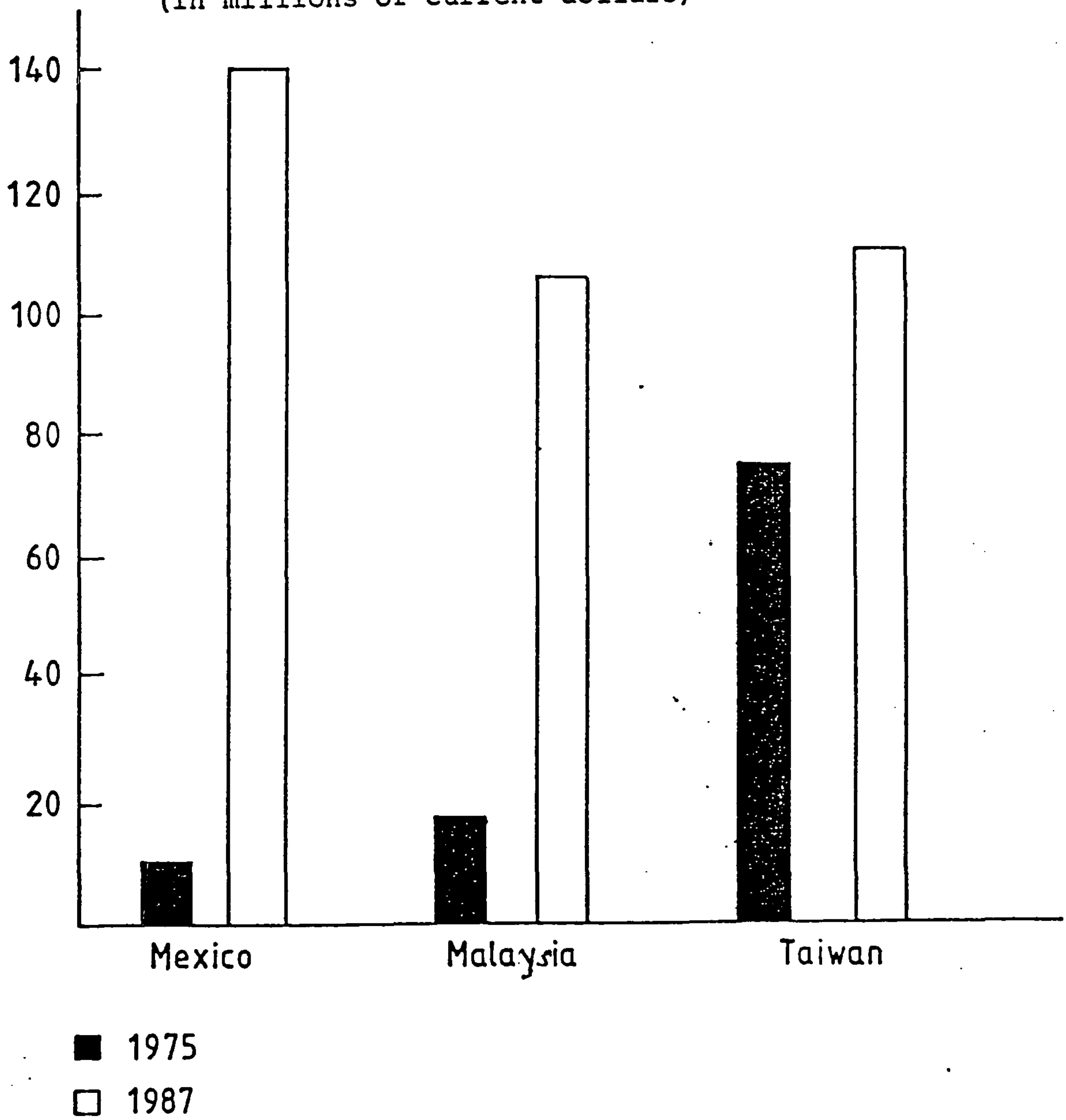


R.O.W. = Rest of the World
N.I.C. = Newly Industrialized Countries (Korea, Taiwan, Singapore, Hong Kong)

Source: U.S. DOC, ITA Printouts, 1988.

Figure 3.10

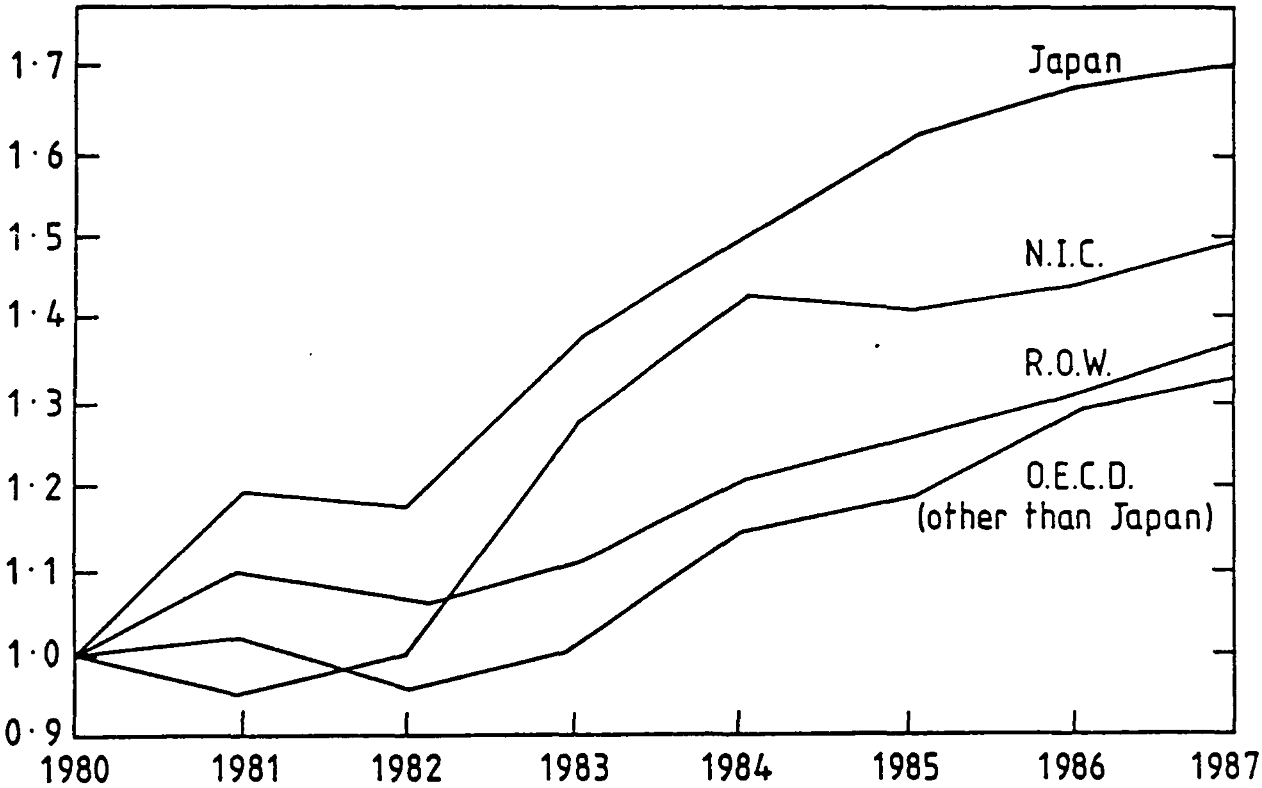
Imports of Manufactured and Assembled Products from Selected Countries, United States, 1975 and 1987 (in millions of current dollars)



Source: U.S. DOC, ITA Printouts, 1988.

Figure 3.11

Exports of Advanced Technology
Products to Selected Geographic Regions,
United States, 1980-1987
(Index 1980 = 1.00)



NIC = Newly Industrialized Countries (Korea, Taiwan, Singapore, Hong King)

ROW = Rest of the World

Source: U.S. DOC, ITA Printouts, 1988.

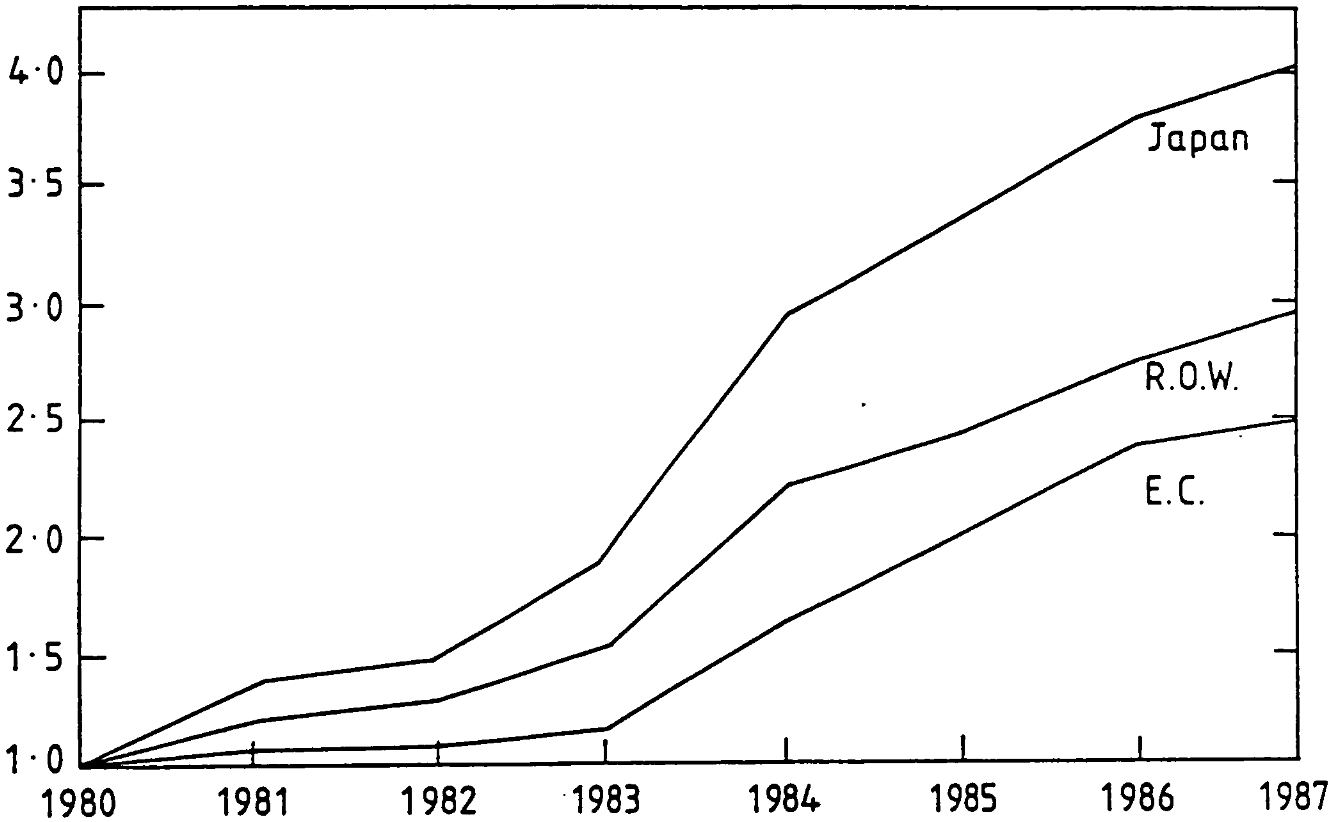
place since 1982. U.S. exports to OECD nations increased by some 30 percent during the 1980 to 1988 period.

Trends in U.S. imports of advanced technology goods during the 1980 to 1988 period show very dramatic increases (Figure 3.12). Japan was the principal beneficiary of U.S. imports of advanced technology products, an increase of over five-fold in the value of their exports to the U.S. All other nations increased their exports to the U.S. by a factor of two or more during the 1980 to 1988 period.

The trade in electronics sets a typical pattern for advanced technology products. Electronics represents the largest subsector of advanced technology industries and includes communications equipment, computer and business equipment, scientific and analytic instruments and electronic components, but excludes consumer electronics. In 1980 the electronics sector accounted for about 36 percent of trade in advanced technology products. In 1985, the electronics sector represented about half the total U.S.trade in advanced technology goods. A rapid increase in the electronics sector resulted in increased U.S. exports, with total electronics exports in 1988 increasing by 25 percent relative to total advanced technology exports. This increase was impacted by increased U.S. exports to the Southeast Asian NICs. A partial explanation for this increase is the low cost labour in these

Figure 3.12

Imports of Advanced Technology
Products from Selected Geographic Regions,
United States, 1980-1987
(Index 1980 = 1.00)



ROW = Rest of the World

Source: U.S. DOC, ITA Printouts, 1988.

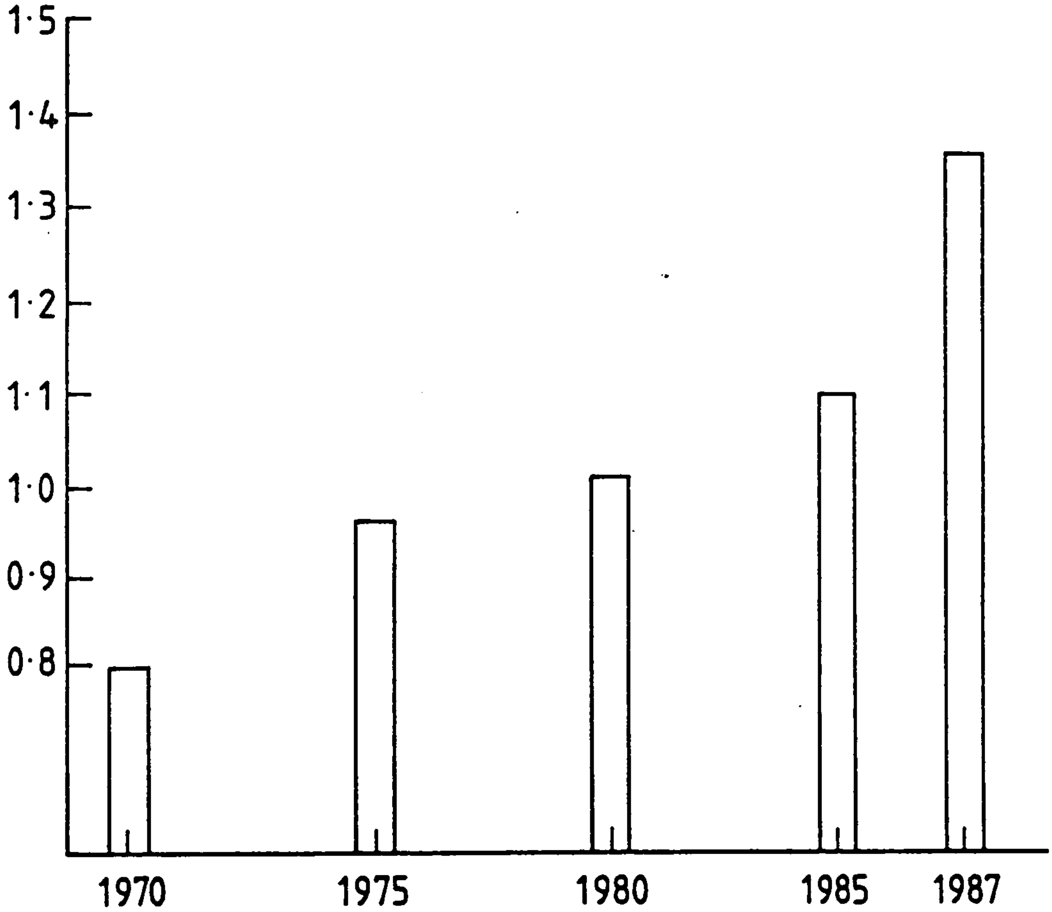
Southeast Asian nations and the increased tendency for U.S. electronics firms to take advantage of these lower labour costs.

U.S. imports of electronics products from the Southeast Asian NICs also showed a significant increase (by a factor of five), a trend which can be readily explained by identifying these imports as semi- or fully-finished products shipped back to the U.S. market after assembly operations abroad (Figure 3.13). During the 1980 to 1988 period, U.S. exports of electronic products to Japan increased at about the same rate as total advanced technology exports.

Several summary observations can be readily made from the analysis presented above and summarized in Figure 3.14. America's traditional trade surplus in advanced technology goods has declined over the 1980 to 1988 period at a rate only slightly slower than the deterioration of the overall U.S. international trade balance. The overall U.S. advanced technology trade balance declined 93 percent from 1980 to 1988, as compared with a decline in total U.S. trade of 97 percent. The fact that the United States has lost its dominant status as an exporter of advanced technology goods may be of grave significance with regard to science and technology trends in the U.S.

Figure 3.13

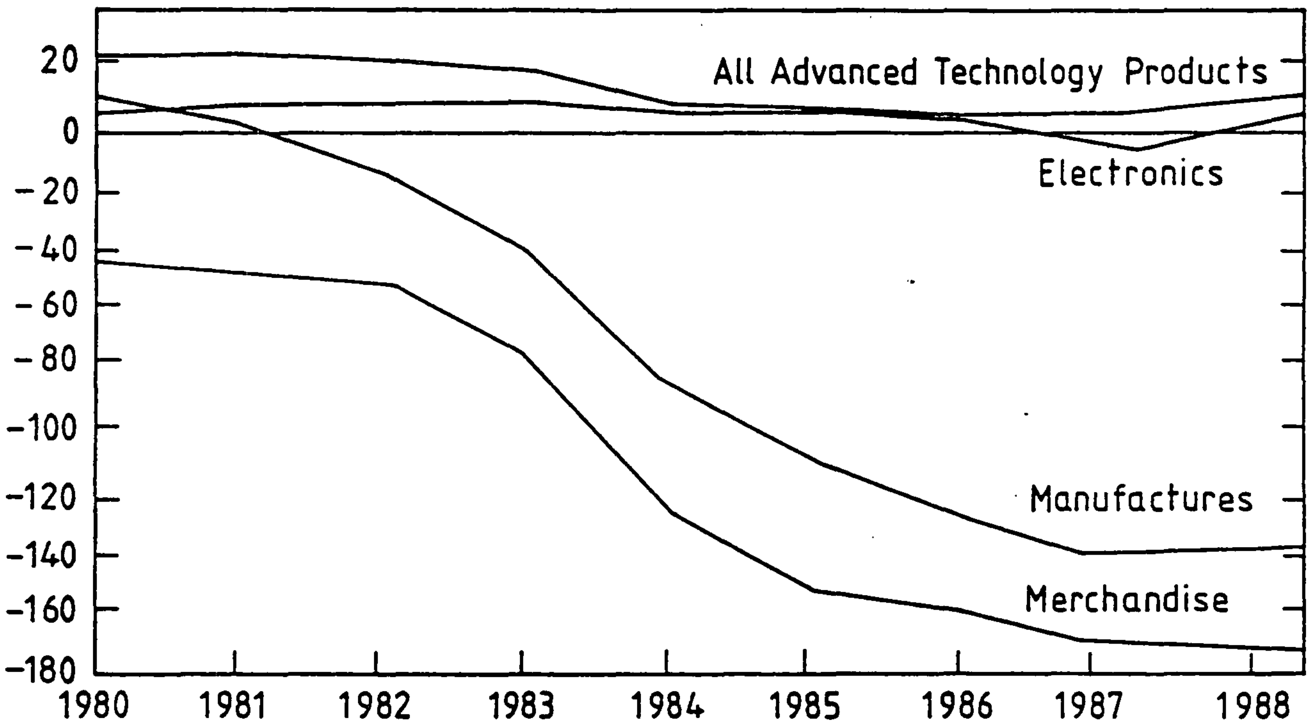
Imports of Semifinished Microelectronic
Products from Indonesia, Philippines
and Barbados, United States, 1970, 1975, 1985, 1987



Source: U.S. DOC, ITA Printouts, 1988.

Figure 3.14

Trade Balance by Type of
Product, United States, 1980-1988
(in millions of current dollars)



Source: U.S. DOC, ITA Printouts, 1988

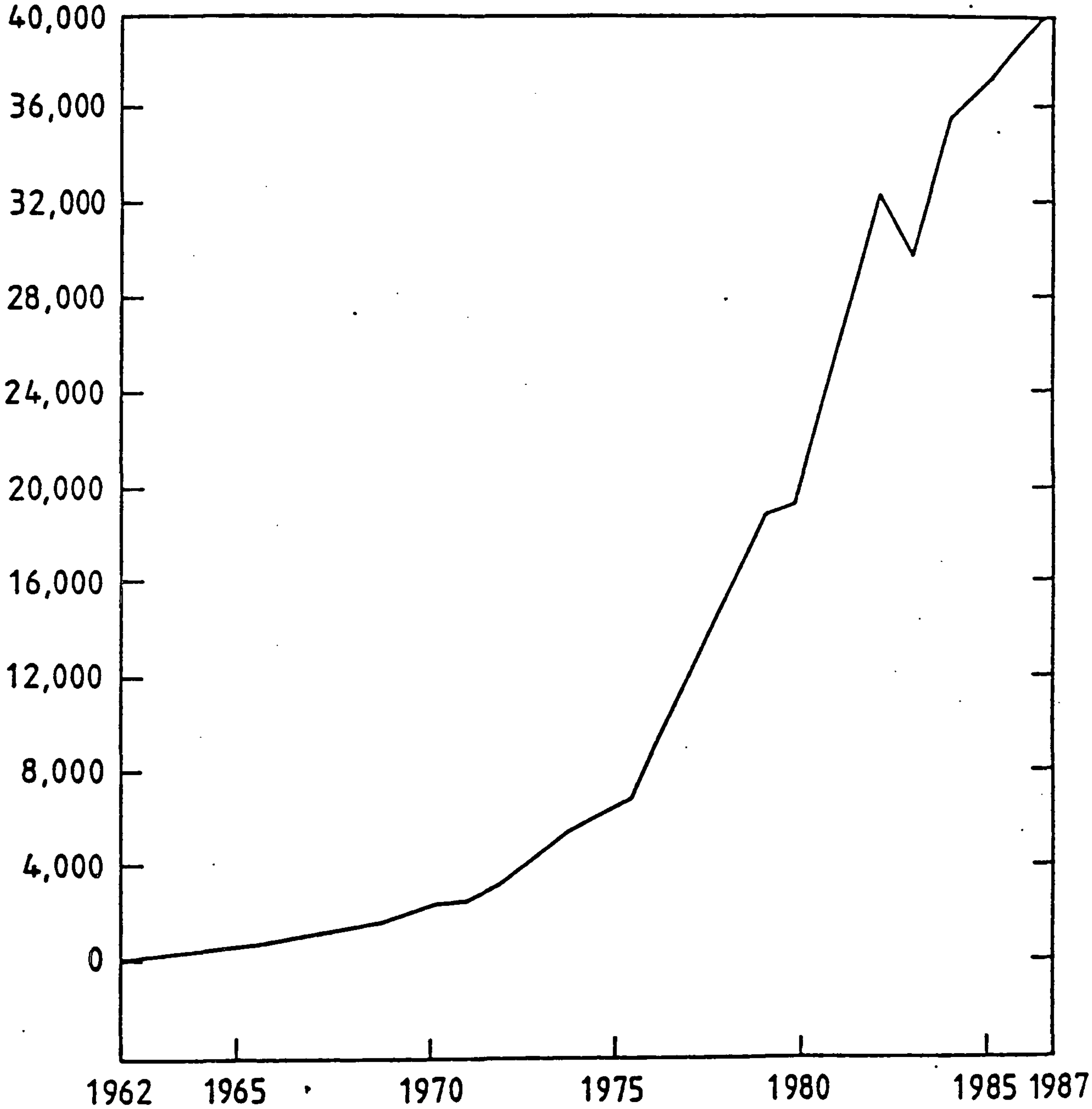
3.3.3 Japan: Changes in the International Trade Characteristics

Total exports from Japan increased from about $4 billion in 1960 to $240 billion in 1988. Imports during this period increased also, but at about one-half the rate of exports. In 1960 Japanese imports stood at $4.5 billion, approximately the same magnitude as exports, while in 1988 Japan imported goods valued at about $150 billion. The Japanese balance of payments fluctuated during the 1960 to 1980 period, but increased tenfold during the 1980 to 1988 period. In 1981 the Japanese had a positive trade balance of about $9 billion, in 1988 this trade balance had increased to about $90 billion. Japanese trade balances in advanced technology products show a gradual increase in the 1962 to 1975 period, and a very rapid growth from 1975 to 1987 (Figure 3.15).

However, while the Japanese have significantly increased their exports since 1980, Japanese imports have increased at a more rapid rate during this time (Figure 3.16). The rapidly increasing rate of Japanese imports is the result of the industrial demands brought about by the continuous and secular increases in Japanese industrial production shown in Figure 3.17. The Japanese terms of trade show relative stability during the 1980 to 1984 period, a very rapid increase in 1984, 1985, and 1986, and relative stability between 1987 and 1988 (Figure 3.18).

Figure 3.15

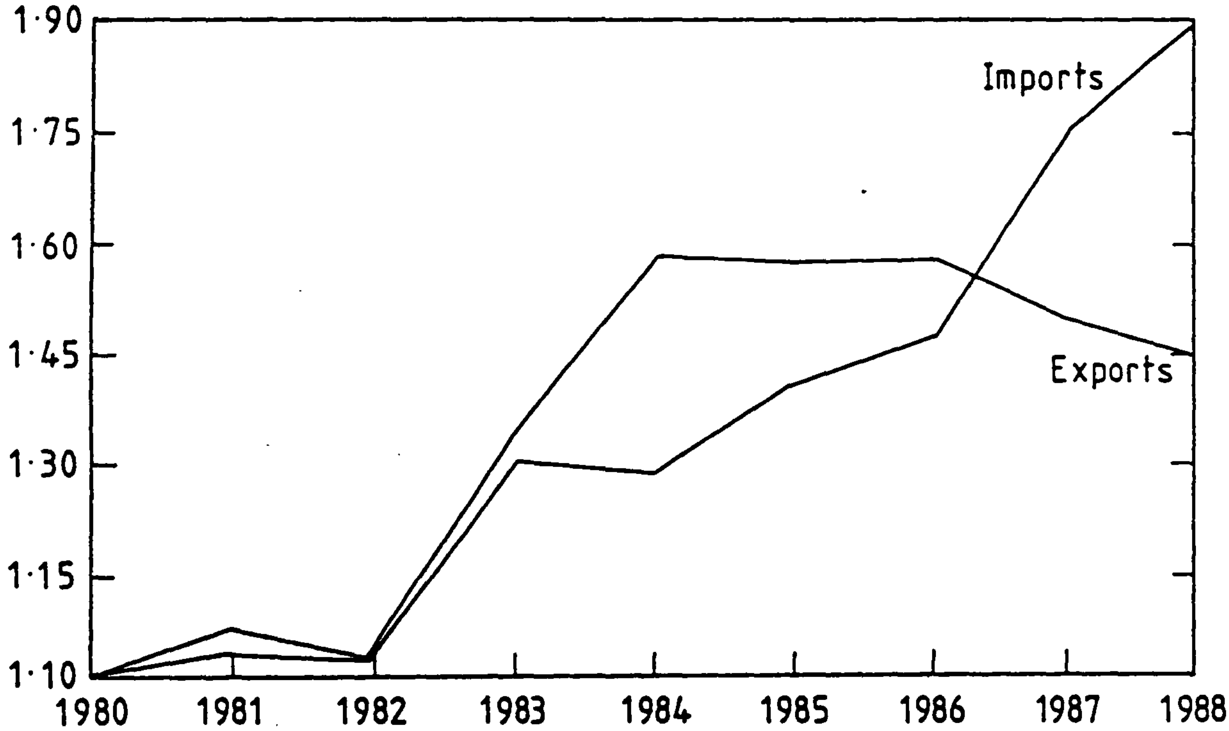
Trade Balance of Advanced Technology Products, Japan 1962-1987 (in millions of current dollars)



Source: Japan MOF Printouts, 1988.

Figure 3.16

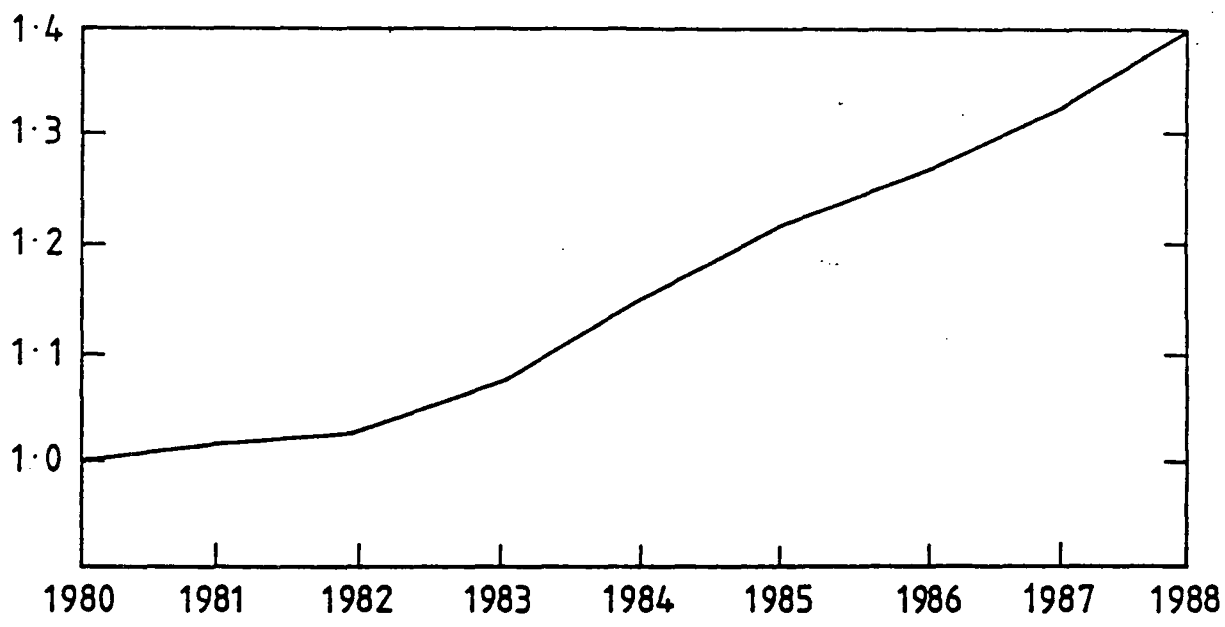
Total Imports and Exports, Japan
1980-1988
(Index 1980 = 1.00)



Source: Japan MOF Printouts, 1988.

Figure 3.17

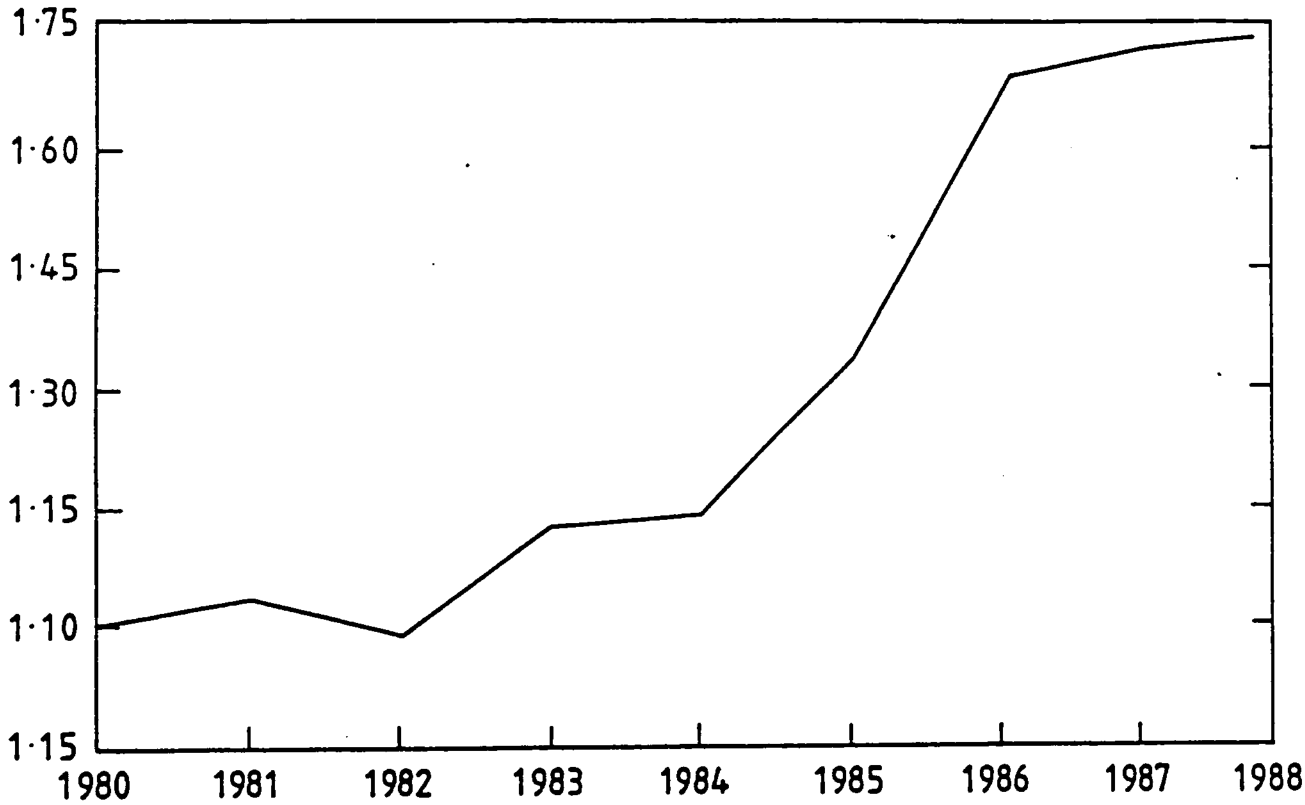
Industrial Production, Japan
1980-1988
(Index 1980 = 1.00)



Source: Japan, MOF Printouts, 1988.

Figure 3.18

Terms of Trade, Japan
1980-1988
(Index 1980 = 1.00)



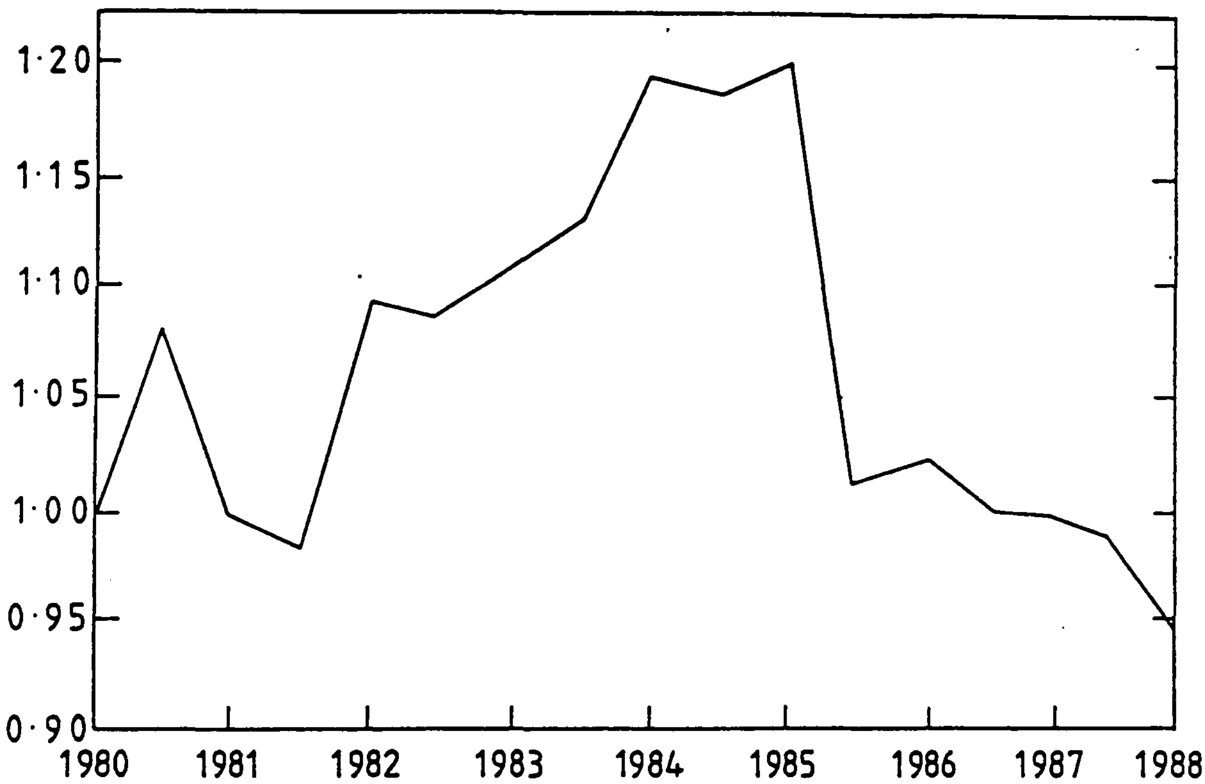
Source: Japan, MOF Printouts, 1988.

The behaviour of the Japanese international trade indicators reflect typical characteristics of international trade in a country with increasing industrial production and endowed with comparative advantage over other nations. The Japanese comparative advantage allowed Japan during the 1965 to 1975 period to capture domestic markets, and from 1975 onwards, to pentrate increasingly into world markets. The increasing industrial production in Japan, in turn, has created demand for increasing inputs (i.e., raw materials, equipment, machinery, etc.). Some of that demand may be satisfied from domestic sources, but some proportion of these inputs are imported. Thus, together with increased exports, Japan also increased its imports. Figure 3.19, which shows the volume of Japanese exports relative to Japanese imports for the 1980 to 1989 period, clearly illustrates this point.

The industry group in Japan, which comprises machinery, electronic and microelectronic products, transportation equipment (including passenger vehicles) and instruments, has experienced a significant increase in its share of total Japanese industrial production from 33 percent in 1975 to slightly over 44 percent in 1988 (Table 3.3). Exports of Japanese machinery and equipment in the 1960 to 1988 period have increased at a much more rapid rate than imports of the same products, and the trade balance for such products has increased ten-fold since 1980 (Table 3.4).

Figure 3.19

Value of Total Exports Relative to Total Imports, Japan 1980 - 1988
(Index 1980 = 1.0)



Source: Japan MOF Printouts, 1988.

Table 3.3

Industry Group Share of Total Value-Added in Japanese Manufacturing, 1975-1987

	Total	Basic[1/] Industries	Processing& Fabricating[2/] Industries	Other[3/] Industries
1975	100.0	39.6%	33.3%	27.0%
1976	100.0	39.3	34.4	26.4
1977	100.0	39.2	34.7	26.1
1978	100.0	40.2	33.5	26.3
1979	100.0	42.1	32.9	25.0
1980	100.0	41.3	34.4	24.2
1981	100.0	39.0	36.3	24.6
1982	100.0	38.3	37.0	24.7
1983	100.0	37.2	38.1	24.7
1984	100.0	37.1	39.4	23.5
1985	100.0	36.4	40.3	23.2
1986	100.0	34.4	42.0	23.6
1987	100.0	33.7	44.1	22.2

1/ Processing and fabricating industries include nonelectric machinery, electric machinery, transportation equipment and precision instruments.

2/ Basic industries include lumber and wood products; pulp, paper and paper products; chemicals and related products; petroleum and coal products; plastic products; rubber products; nonmetallic mineral products; steel; nonferrous metals; and fabricated metal products.

3/ Other industries include food products; tobacco products, beverages, and feed; textile mill products; apparel and made-up textile products; furniture and fixtures; printing and publishing; leather and leather products; and other manufacturing.

Source: Ministry of International Trade and Industry, Census of Manufacturers: Report of Industries, 1988

TABLE 3.4

Japanese Machinery and Equipment Trade with the World, 1960 - 1987

(in billions of current dollars)

YEAR	EXPORTS	IMPORTS	BALANCE
1960	4.1	4.5	-0.4
1967	10.4	11.7	-1.3
1968	13.0	13.0	0.0
1969	16.0	15.0	1.0
1970	19.3	18.9	0.4
1971	24.0	19.7	4.3
1972	28.6	23.5	5.1
1973	36.9	38.2	-1.3
1974	55.6	62.0	-6.4
1975	55.8	57.9	-2.1
1976	67.2	64.8	2.4
1977	80.5	70.8	9.7
1978	97.5	79.3	18.2
1979	103.0	110.7	-7.7
1980	129.8	140.5	-10.7
1981	152.0	143.3	8.7
1982	138.8	131.9	6.9
1983	146.9	126.4	20.5
1984	170.1	136.5	33.6
1985	175.6	129.5	46.0
1986	209.2	126.4	82.7
1987	229.2	146.2	79.7
1988	243.0	149.5	93.5

SOURCE: "International Economic Indicators", International Trade Administration, Department of Commerce, 1989.

Indeed Japanese increases in advanced technology product exports is a direct result of the growth of Japanese advanced technology sectors. Imports of advanced technology products have also increased during the same time period, in order to provide the Japanese economy with required inputs (Table 3.5). As the data show, Japanese exports of advanced technology goods have dominated imports during the last three decades. Moreover, Japan's export to import ratio increased over time. This increase in Japan's exports and relatively stable level of imports, during the last decade, resulted in the increased positive trade balance for Japan in advanced technology products. As shown in Table 3.5 Japan's trade balance increased from about $2 billion in 1970; to $21 billion in 1980, and to almost $49 billion in 1987.

Analysis of the export content suggests that a significant proportion of Japan's exports to the U.S. is represented by microelectronic products, followed by motor vehicles, machine tools, and machinery of all types.

Japan's imports from the U.S. during this time period increased also, but at a much lower rate. A significant proportion of these imports consisted of machinery and related products used in the manufacture of the advanced technology goods. The type and kind of imports however have changed. Whereas in in the 1970's the emphasis was on raw materials (imported principally from developing regions), during the 1980's the emphasis has shifted to machinery and equipment (imported principally from industrialized regions).

This change in emphasis as to the origin of Japanese imports from developing regions to industrialized countries is illustrated in Figures 3.20 and 3.21.

Information presented in Figures 3.22 and 3.23 traces the change in Japanese export destinations for the 1980 to 1988 period. The dramatic increase in Japanese exports to industrialized regions, can be clearly seen from the information provided in Figure 3.22.

Figure 3.23 illustrates the growth of the U.S. as the destination for Japan's exports.

As shown in Figure 3.23, whereas, Japanese exports in the 1980 to 1987 period, to Germany and France, remained at a relatively stable level, Japan's exports to the U.S. have increased dramatically.

TABLE 3.5

Japanese Advanced Technology Trade with the World, 1962 - 1987

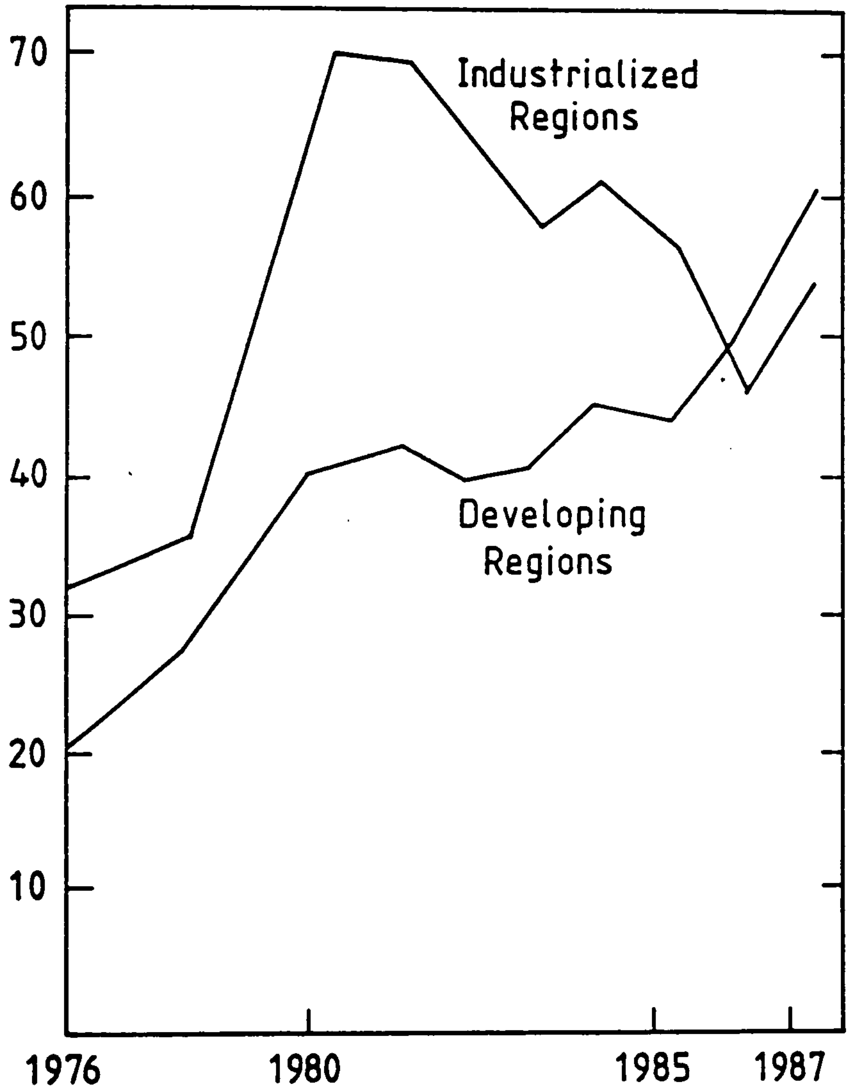
(in billions of current dollars)

YEAR	EXPORTS	IMPORTS	BALANCE
1962	0.6	0.6	0.1
1965	1.3	0.7	0.6
1970	4.0	2.0	1.9
1975	11.1	4.2	7.0
1976	14.2	4.9	9.4
1977	17.6	5.3	12.2
1978	23.2	6.9	16.4
1979	26.1	9.3	16.7
1980	32.5	11.2	21.3
1981	41.0	12.1	28.9
1982	36.4	11.1	25.3
1983	38.2	10.2	27.0
1984	46.7	11.1	35.0
1985	48.0	10.7	37.3
1986	57.8	9.8	48.0
1987	61.2	12.6	48.6

Source: MITI printouts, 1988.

Figure 3.20

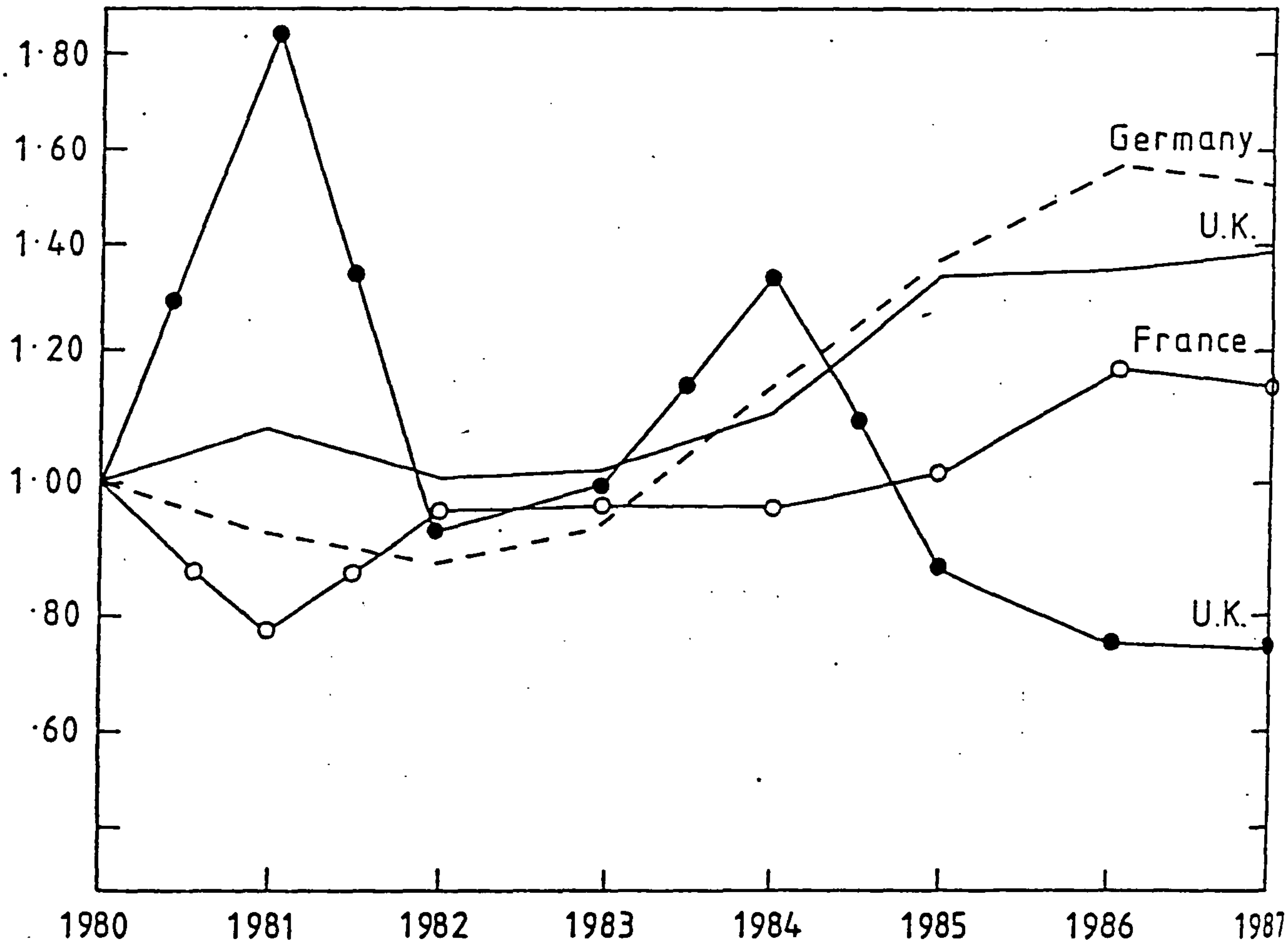
Total Imports from Industrialized
and Developing Regions, Japan 1976-1987
(in millions of current dollars)



Source: Japan MOF Printouts, 1988.

Figure 3.21

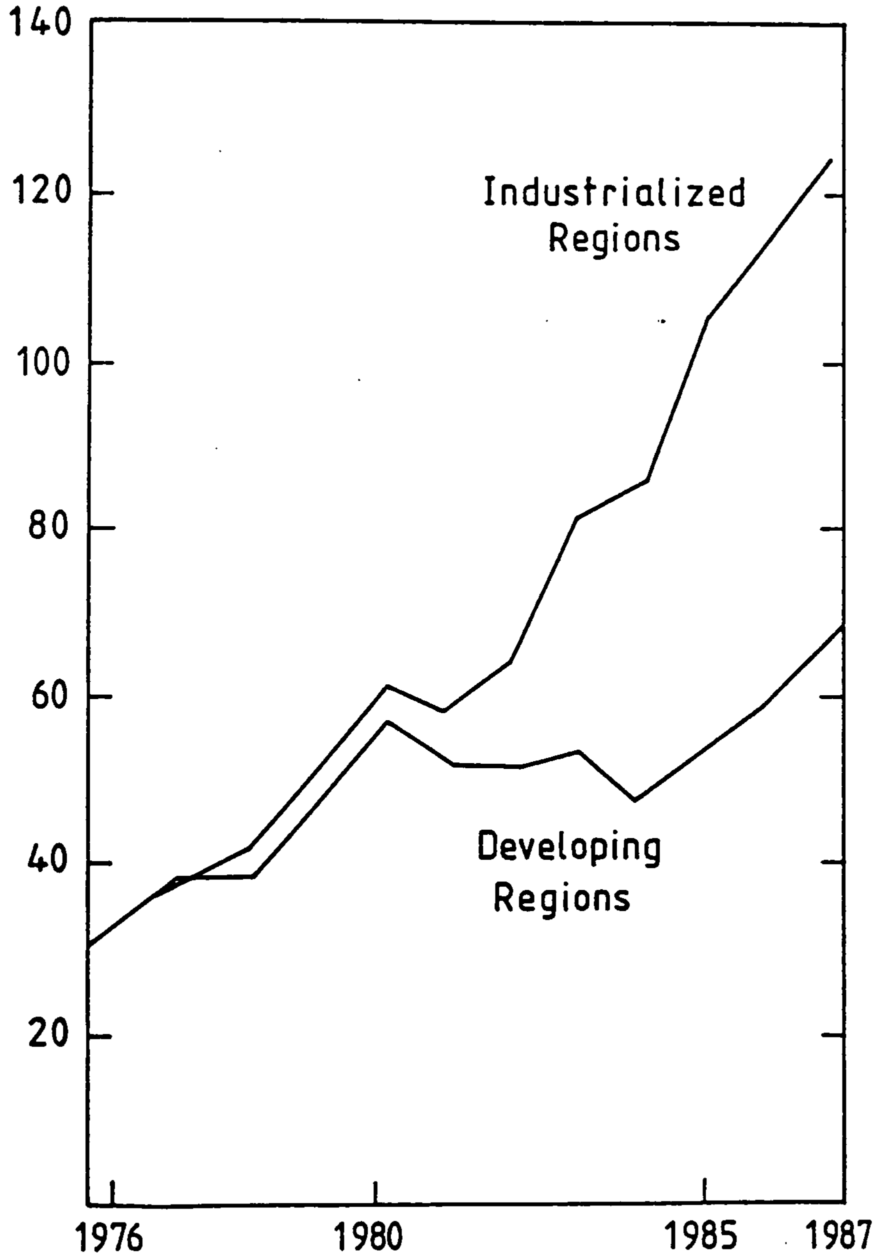
Imports of Manufactures from Selected Countries, Japan 1980 - 1987 (Index 1980 = 1.00)



Source: Japan, MOF Printouts, 1988.

Figure 3.22

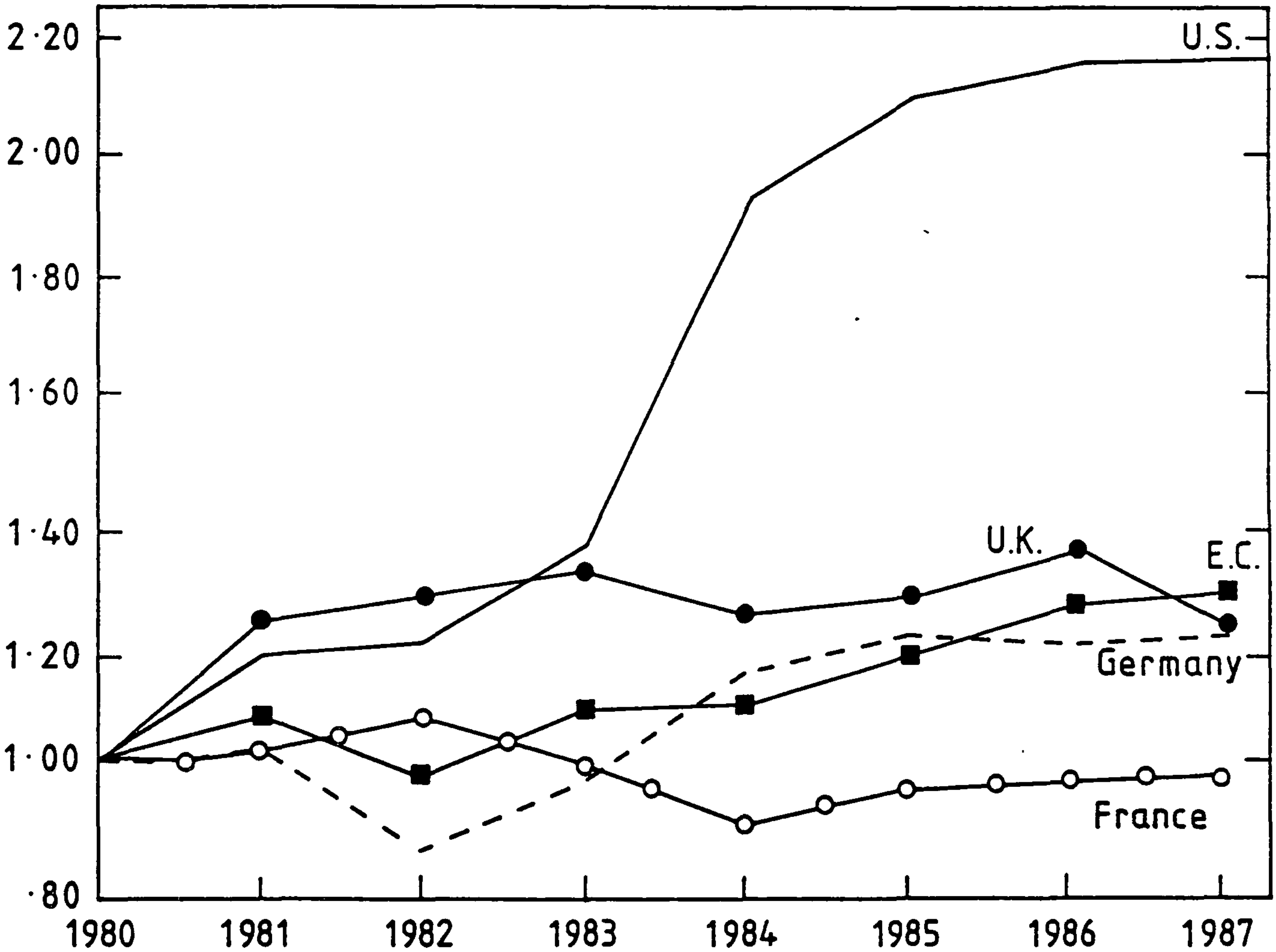
Total Exports to Industrialized and Developing Regions, Japan 1976-1987 (in millions of current dollars)



Source: Japan, MOF Printouts, 1988.

Figure 3.23

Exports of Manufactures to
Selected Countries, Japan 1980-1987
(Index 1980 = 1.00)



Source: Japan, MOF Printouts, 1988.

3.3.4 Summary

As the statistics presented above indicate, during the last three decades Japan was able to increase its domestic industrial production significantly, even dramatically, particularly the production of advanced technology goods. Concurrently, Japan was able to increase its exports of advanced technology products and obtain increasingly larger world market shares for various microelectronic devices, machine tools, scientific instruments, machinery, and other products.

Much of this increase in Japanese exports took place at the expense of other industrialized countries, including the U.S., Germany, the U.K., and France. Not only were the Japanese able to replace advanced technology products of these industrialized nations in the world markets, but the imports of Japanese products replaced domestic manufacture of these products within the national boundaries of these industrial nations.

The Japanese success story is in itself a unique development in the annals of international trade, in particular because during the last three decades the Japanese were able to replace advanced product lines manufactured by countries that had been the market leaders for such products ever since these product lines appeared on the market. The replacement of the microelectronic products manufactured by the U.S. and of machine tools produced by German and U.S. tool makers, are examples of the Japanese success.

Of singular importance is the fact that Japanese increases in the manufacture and sales of these products were accompanied by the deliberate and comprehensive intervention of the Japanese Government in the market functions for these products at both domestic and international levels. It can even be argued that the growth of the Japanese economy took place because of the intervention of the Japanese Government in free market functions. (See Chapter 12 for a discussion of these issues).

Conversely, the governments of Germany, the U.K. and the U.S. elected not to interfere in the free market functions. The French government choose to interfere in free market functions, but limited this interference to the large government controlled enterprises. Thus, whereas these governments followed more or less the prescriptions of classical economic theory, the Japanse Government chose to break most of the rules prescribed in classical economics for optimum economic growth policy.

The indisputed growth of the Japanese economy (as well as of some other countries, such as NICs) in spite, or because of, an almost complete disregard for classical economic theory was noted by economists, and analyzed in some detail. As a result of this analysis, the rules of classical economics were essentially abandoned and a "new" international trade theory promulgated. Not all economists subscribe to all of the components of this new theory. Essentially, all economists agree on the basic premises of the new theory, including the assertion that appropriate government intervention in free markets may provide a nation with comparative advantages in selected sectors of the economy. The following section traces the development of this new theory of international trade.

3.4 DEVELOPMENT OF THE "NEW" INTERNATIONAL TRADE THEORY

The development of the "new" international trade theory and abandonment of the classical economic prescriptions for government policies to guide a nation's economic growth took place over several decades. It initially consisted of modifications to certain assumptions of the Heckscher-Ohlin model of international trade.

One such development concentrated on the innovation process (Linder, 1961; Vernon, 1970; Bhagwati, 1983). Arguments here depart from the classical or Heckscher-Ohlin models in that the implicit assumption that information is an instantaneous and free good is abandoned. Instead, this theory builds on the premise that information concerning technologies, production processes, markets, etc. is of cardinal importance and that such information disseminates only gradually over time and space (Krugman, 1983;

Bhagwati and Brecher, 1980). While classical trade theory relies on international differences in relative prices and costs to explain the composition of trade, this trade model stresses that in a world of imperfect information, explicit technical and related knowledge regarding innovation, technology advances and related factors are of paramount importance, much more important indeed, than comparative costs in determining the pattern of trade, especially international trade in advanced technology industries (Gruber, Mehta and Vernon, 1967; Gruber and Vernon, 1970; Helpman, 1981).

Linder was the principal author of this new theory of international trade, and proposed it in his "An Essay on Trade and Transformation" published in Stockholm in 1961. Since 1961, Linder's theory has been developed into two separate but overlapping strands: the neotechnological theory and the differentiated-goods theory (Hufbauer, 1970).

The neotechnological theory postulates that international trade takes place because differences exist in the attributes of firms and industries among nations which participate in international trade. These differences affect the relative costs of production and therefore result in differences of comparative advantages. According to Gray (1980):

> The neotechnological theory identifies the various stages of development of a product from the first non-

> standardized to the ultimate standard version under the label of "product differentiation." This concept of differentiation has little or no relevance to the Chamberlinian concept which forms the basis of the differentiated-goods theory. To the extent that Chamberlinian product differentiation is allowed for in the neotechnological theory, it is identified through such measures as advertising and other marketing expenditures.
>
> The differentiated-goods or variety theory is based essentially on very close similarities of demand characteristics in trading nations so that goods made domestically will be distinct from goods made abroad only by their differentiation in design features and quality.

According to the neotechnological theory of trade, innovation, technology advances, and product development are a function of the local (i.e., national) environment, and reflect local needs, as well as the local availability of knowledge and resources (Hufbauer, 1970; Johnson, 1957; Batra and Ramachandraw, 1980). Domestic manufacturers, because of their advantage in possessing local information, have distinct advantages regarding the development of products to meet the needs and characteristics of the home or local market. These commodities, manufactured initially for the home market, are then exported to other nations with similar needs. The marginal cost of production for the export market is relatively low because the production costs for the home market "absorb" the initial high unit production costs. Similarity rather than difference therefore forms the basis for international trade in these commodities. The pattern of innovation therefore determines the pattern of trade and advantage in required information rather than comparative economic cost advantages determining the location (i.e., country) of the producer of the commodities in international trade. Two formulations of these models focus on different aspects of product development.

The Product Differentiation Theory attributes trade to a combination of (a) general similarities in consumer demands among countries, and (b) specific differences in consumer tastes. This theory postulates that a number of nations may produce and trade the same commodities among themselves, but each country's version of the commodity will appeal to a slightly different segment of the market. Commodities in this theory may be differentiated in terms of:

(a) initial and life cycle costs;
(b) performance characteristics;
(c) styling;
(d) operations and maintenance requirements;
(e) durability; etc.

Domestic producers of such commodities develop a version suited to the general demand (including specific tastes and characteristics) of their domestic market and export this version to other countries with similar tastes (Aquino, 1983; Casson, 1982). Population subgroups or minorities in any country with tastes significantly different from those represented by the majority of the population, can satisfy their demands for commodities through imports from countries with product lines which do satisfy their demands (Bergsten, 1980; Cline, 1983). Note that while this discussion is presented in terms of consumer goods, it is equally valid for industrial and commercial goods.

Why do domestic firms not produce enough different commodities to satisfy all segments of the market? In some cases they try. In most other cases, factors such as economies of scale, technical know-how and capital expenditures required for production, provide the foreign producer with a significant advantage over a domestic enterprise in a specific segment of the market (Gray, 1980; Helpman, 1981; Katz, 1984; Mowery, 1983).

The Product Cycle Theory of international trade postulates the desirability of international trade in commodities, produced in any one country, as the required information concerning the commodity and the markets become available over time. Vernon (1970) divides the product cycle of a commodity into three phases.

a) In the early stages of commodity development, production of the commodity is not standardized, product characteristics still need to be developed and adopted to consumer tastes, and the dimensions of the market are unknown. These considerations argue for a production location which allows the maximum communications among producers, suppliers and consumers. Production costs are important but flexibility in production is essential. Location of production facilities near the markets is therefore mandatory in this initial phase.

b) In the second phase, as the product matures, production becomes more standardized and the need for close communication with the market and production and flexibility becomes less important. Possibilities for economies of scale and mass production arise, and a concern for production costs begins to assert itself. The market for the commodity begins to expand and the commodity may be exported to other countries with similar tastes and characteristics. At some point in time the manufacturer of the commodity may decide to set up production facilities in foreign countries for a number of reasons. These may include reduction in production costs to improve competition with newly arising foreign manufacturers. The establishment of foreign production facilities raises the possibility that the home markets or third countries may be serviced from these new foreign production facilities.

c) In the final phase the product is fully standardized and its production can be readily explained by the Heckscher-Ohlin model. The existence of well established and easily accessible international markets nullifies any informational advantage of the high-cost producer, while the accessibility of the technology reinforces the concern for cost.

Closely related to the product cycle theory is the technology gap model (Mansfield, 1985). According to this model the initial developers of a commodity with specific technological features enjoy technological and/or managerial advantages which allow these commodities to be traded across national boundaries (Majumdar, 1979). The technology gap model is especially applicable to commodities with advanced technologies (Pack and Westphal, 1986; Rosenberg and Frischtak, 1984). Late-comers under the technology gap model must rely on cost advantages in order to achieve a share of the international market.

Two related issues which have recurred at several points in the discussion of these new international trade models are economies of scale and the role of international trade in extending the boundaries of national economies. Even in the absence of international differences in prices and therefore the cost of commodities, trade may allow a nation to specialize in the production of certain commodities and by so doing to take advantage of certain economies of scale in production, thus increasing world output (Puli and Wibe, 1980; Maskus, 1983). On the other hand, large scale national economies of scale may convey relative cost advantages to these domestic producers.

Linder (1961) states an obvious, but important point, that international trade is nothing more than the extension of a country's own domestic economy across national borders. In this sense, the sources of international trade should be similar to the sources of domestic trade, and this is certainly the case. One sees differing factors of production, endowments, specialization, economies of scale, product differentiation and innovation as much at work domestically as internationally. However, Linder's insight has a further implication. International trade tends to draw economies together and integrate them more fully. With interdependence comes vulnerability, which for any one nation produces effects internally and ramifications throughout the international trade network.

Analyses of international trade and related issues for a set of selected high technology commodities (microelectronics, machine tools and advanced materials), adhere to the general features of the <u>information/product differentiation/product cycle</u> theories of international trade essentially completely.

It is, however, the need for very specific <u>information</u> or <u>knowledge</u> that determines the success or failure of a commodity production in a specific location (i.e., country). Note that the terms information and knowledge emphasized in the previous sentence cover an exceptionally broad spectrum which includes timely and early outputs from R&D programmes, "know-how" of technological advances, ability to insert advanced technologies in a production processing, and knowledge of market demand. Some of this information or knowledge may be acquired by extensive effort, some of which depends on the existing structure of the economy, and certainly government policies play a major role.

The classical international trade theory offers no explanation for the emergence and dominance of certain technological advances in specific countries. Gruber <u>et al.</u> (1967) judged the contributions of the classical international trade theories, as an explanation of the technology development process for a particular nation, to be marginal or contradictory. Gruber's judgement of the "new" theory, as it explains the reasons for the emergence of certain technologies in certain nations, is much more positive. It is illuminating to quote Gruber's (1967) principal conclusions.

> In the last ten or fifteen years, the field of international trade theory has been in continuous ferment. The received doctrine drawn from the mainstream of Smith-Ricardo-Mill-Marshall-Heckscher-Ohlin has been re-examined from many different angles. Sometimes, there have been strongly revisionist reactions, such as those encountered in the economic development area. In other contexts, the emphasis has been mainly on the further testing and refinement of the doctrine of comparative advantage and the role of factor endowments. . .
>
> Of late, the tendency has been to search for hypotheses which "explain" not only the apparent strength in U.S. exports of manufactured products but also the apparent propensity of U.S. producers of those very products to set up manufacturing facilities abroad (see for example, Polk, Meister, and Veit, 1966; Vernon, 1966). This line of speculation takes off from the observation that entrepreneurs in the United States are surrounded by a structure of domestic demand for producer and consumer goods that is in some respects a forerunner of what will later be found in other countries. Labor is costly in relation to its productivity, while capital is comparatively plentiful, facts which influence the nature of the demand for producer goods. And per capita incomes are high by international standards, a fact which creates unique consumption patterns. This means that entrepreneurs in the United States are likely to be willing to gamble on the innovation of labor-saving and affluent-consumer products at an earlier point in time than their overseas competitors.
>
> The hypotheses go on to project certain characteristic sequences in the foreign trade of products that have been innovated in the United States.

The other principal authors of the new theory of international trade are Krugman (1983, 1984); Dixit and Kyle (1983, 1985); Spencer and Brander (1983); Brander and Spencer (1983, 1984); and Grossman and Richardson (1984), all of which have contributed to the development of the new theory. The thrust of the new theory is not to explain why international trade takes place, but to formulate strategic public policies in the use of international trade as an instrument to improve the economy of a country. As stated by Krugman (1985):

> The new approaches open up the possibility that there may be 'strategic' sectors after all. Because of the important roles now being given to economies of scale, advantages of experience, and innovation as explanations of trading patterns, it seems more likely that rent will not be fully competed away -- that is, that labor or capital will sometimes earn significantly higher returns in some industries than in others. Because of the increased role of technological competition, it has become more plausible to argue that certain sectors yield important external economies, so producers are not in fact paid the full social value of their production.
>
> What all this means is that the extreme pro-free-trade position -- that markets work so well that they cannot be improved on -- has become untenable.

Krugman further suggests that international trade allows a country with an appropriate trade policy to benefit from world markets. According to Krugman, there are two reasons for this.

The first of these is the ability of government policies to secure for a nation a larger share of "rent". "Rent" in economic parlance means payments to an input higher than what that input could earn in an alternative use. In common terminology, the larger share of "rent" translates into large profit margins, significantly larger than those which would allow for payment of labour, capital, operating costs and "reasonable" return or payment for entrepreneurial skills and risk taking.

The second reason is that of external economics in force in many international trade transactions. The role of external economics in advancing international trade as an economic growth vehicle is summarized by Krugman (1985) as follows:

> External economies present a differnt justification for activist trade policies. By an 'external economy' economists mean a benefit from some activity that accrues to other individuals or firms than those engaging in the activity. The most plausible example is the diffusion of knowledge generated in one area to other firms and other sectors. Although external economies are different conceptually from rents, they likewise provide a reason to favor particular sectors. This time the point is not that capital and labor in the sector will themselves earn exceptionally high returns; rather, they will yield high returns to society because in addition to their own earnings they provide benefits to capital and labor employed elsewhere.
>
> The reason why external economies have become more of a trade issue is that, as noted earlier, the reassessment of trade gives technological innovation an enlarged role. Innovation, because it involves the generation of knowledge, is particularly likely also to generate valuable spillovers. So there is now good reason to suspect that trade policy can be used to encourage external-economy-producing activities.

The initial major work in current international economics was published by Krugman (1984). Krugman's basic thesis was that the restriction of certain markets to particular firms results in increased sales of the particular firms not only in the restricted markets, but also in other markets as well. For example, protection of domestic markets not only provides domestic firms with a larger share of domestic markets (because foreign competition is not allowed to sell in these markets), but also results in larger foreign sales by the domestic firms. A very important element in Krugman's analysis is the presence of some form of advantage of size or "economics of scale." According to Krugman, not only do economics of scale allow a firm to reduce its marginal costs of production (because marginal costs fall as output increases), but the increase in output reduces marginal costs due to the "learning curve" phenomenon.

The concept of the "learning curve" assumes that a learning-by-doing relationship operates and that as production increases the firm or industry learns how to undertake further production moves efficiently. The firm or industry is assumed to move downward along its "learning curve."

In the case of microelectronics, the impact of the learning curve results in a reduction in the costs of production by one-half for every time total output is doubled. In the case of international trade, a firm with protected home markets will increae its output more, and in a shorter time, which in turn will allow the firm to reduce marginal production costs. This will allow the firm to compete more successfully and earn higher profits in export markets. A deliberate policy by a government to facilitate such developments is referred to by Krugman as "protection on export promotion."

The impact of tariffs in the "new" theory is to increase the relative disadvantage of foreign firms due to the increased cost of doing business. Domestic firms, under these assumptions, would have lower average costs, while the average costs for foreign firms would increase. Furthermore, because the output of foreign firms would decline (due to reduced exports), the prices charged for goods produced by foreign firms in their domestic markets would increase because of the increased average costs (which increase with reduced output). The impact of subsidies is similar. Subsidies allow domestic firms or industries to export more and reduce their average costs.

The principal element of Krugman's argument is that large outputs allow for a lowering of prices and, therefore, for an increase in the market share. Government policies, therefore, should attempt to increase the output of domestic firms. Another current theory, which prescribes government policies in international trade, has been proposed by Brander and Spencer (1983). The theory is described as follows:

> As an initial situation, imagine a domestic market in which no domestic firms are operating but which is served by a foreign firm. The foreign firm is aware of the possibility that a domestic firm might enter the market but prices in such a way as to deter domestic entry. A tariff in this situation can extract rent from the foreign firm because, up to a point, the foreign firm will just absorb the tariff and not raise domestic prices for fear of enticing domestic entry. A sufficiently high tariff will eventually force the foreign firm to give up this practice of entry deterrence; domestic prices will rise, and domestic entry will occur.

Clearly these theories differ from traditional foreign trade analyses in three fundamental ways. First and foremost, these theories do not assume that government intervention in a nation's free markets is harmful. On the contrary, these analyses suggest that proper government policies may result in benefits (i.e. improved economy) for the country which undertakes such policies. Moreover, these theories dispense with the most cherished principle of classical economics, that of assurance that specific government policies to advance comparative advantage do more harm than good. Secondly, to a certain extent, these models more accuratley replicate the real world as it exists; indeed, Krugman's analysis, while applied in a theoretical manner, does correctly replicate the real activities undertaken by the Ministry of International Trade and Industry (MITI) in Japan to increase the Japanese share of the world market in certain microelectronic products.

Thirdly, and perhaps most importantly, current theories to a significant extent provide blueprints for government policies not only with regard to international trade, but also with regard to the selection of domestic industry sectors which, with appropriate government policies, would increase output as well as domestic and international sales, and therefore improve the domestic economy.

The celebrated example of this, proposed by Spencer and Brander (1983), is the seven characteristics of industry sectors which determine which sectors have the lowest potential for growth in the domestic and international markets.[7] Among these seven characteristics are those which address R&D issues, i.e., characteristics six and seven.

Spencer and Brander (1983) argue that because of the spillover effects of R&D or transfer of technology to other firms, an innovating firm will be unable to appropriate fully the return from R&D. Patent protection can help to overcome this problem, but it has proved less than fully effective, particularly in the international arena. In those industries where there are major problems in appropriating returns from R&D, private incentives can lead to too little R&D from the viewpoint of the best resource allocation within a society. The transfer of technology to other firms confers benefits to society that are not taken into account by the innovating firms.

This traditional argument for government subsidization of R&D, arising from the existence of substantial spillover effects of R&D, depends on taking a world view of welfare, rather than the more national view in which the gains and losses of other nations are not taken into account. From a domestic viewpoint it is important whether the externalities are conferred on domestic or foreign firms. If there is oligopolistic rivalry between foreign and domestic firms, any spillover of domestic R&D to foreign firms is likely to reduce the rents earned by domestic firms in international markets. This effect could lower the domestic benefit from R&D subsidies. Domestic policies can be designed to reduce the extent of spillovers of domestic R&D to foreign firms.

Even if a firm is not first in innovating a product, it may still do well if it is in a position to copy and improve on major innovations being made elsewhere. If there is international rivalry, this means that a domestic industry will be better off if it is in a position to take maximum advantage of spillovers of R&D from foreign firms. For example, it has been suggested (e.g. Weinstin, et al., 1984) that the Japanese semiconductor industry has benefited substantially from U.S. R&D in basic technologies. By concentrating on process technology, the Japanese were able to replicate or adapt U.S. designs at low cost. This enabled them to capture in a relatively short time a large share of the market in consumer products using semiconductors.

On the other hand, if there are no spillovers of R&D so that domestic firms can appropriate the full return from R&D, an increase in domestic R&D due to government subsidies can set the stage for an increase in profits from export sales, which more than exceeds the cost of the R&D subsidy. Just as in the case of capital subsidies, this policy is effective to the extent that it leads foreign firms to reduce their R&D levels (Spencer and

Brander, 1983). Domestic firms alone may not be in a position to produce such a response. If a domestic firm announces that it is substantially increasing its expenditure on R&D, this may not be entirely convincing or credible to foreign firms who may decide to continue with their R&D plans, making the domestic increase in R&D unprofitable. On the other hand, increased domestic expenditure on R&D would be expected as a natural response to a domestic subsidy to R&D and could well indicate to foreign firms that their rsearch in this area is less likely to pay off. Hence supporting R&D-intensive industries could be one way of obtaining a greater share of future winning industries.

There also may be a connection between government support of R&D and capital investment in the early stages of a product's development, and the future structure of the industry in terms of the eventual number of firms in the industry and the timing of their entry. In the early stages of a product's life cycle, an initial innovating firm may have a temporary monopoly of the product. After a time imitators enter, reducing the profits of the innovating firm and bringing the industry into what is often called its "mature phase." Government subsidies to investment by the original firm can allow it to enjoy greater economies of scale, making entry by other firms less profitable. There may be a domestic gain if such policies reduce the number of foreign entrants or delay the entry of foreign firms.

3.5 SUMMARY

The modifications of the classical economic theory, as discussed above, began with the relaxation of a few of the "rules" or assumptions of classical economic theory. Over time, such modifications increased in number and importance, and clearly depicted more accurately the "real world" as well as the actual behaviour of international trade activities. Among such modifications were the assumption that different firms may have different technology attributes that result in different relative costs of production; that technology advances reflect local needs and availability of local resources; that economies of scale play an important role in the determination of production costs; that a product cycle contributes to differences in a country's development of advanced technology products at any one time; and that external economies present another reason for the rapid growth of advanced technology in one country and the very modest performance of the same technology in another nation.

The most important common characteristic for essentially all of these modifications is the ability of the government of a country, via appropriate policies, to direct the magnitude of the determinants of the production in a nation's economy, as well as the magnitude of foreign trade, in order to reduce negative impacts on the performance of the country's economy.

The "new" theory, for example, allows government policies to improve the technology attributes for the firms in an advanced technology sector in order to reduce manufacturing costs. The modifications in the classical theory also allow the government to encourage the formation of larger scale manufacturing facilities, again in order to reduce manufacturing costs. Finally, the new theory allows governments, via appropriate policies, to stimulate the growth of a certain sector of the economy, at a specific time, in order to take advantage of the increased demand as indicated by the product cycle.

While the new international trade theory may not explicitly require intervention in free market performance by government policies, it allows such intervention to take place. As discussed in Chapters 7 to 11, the governments of Germany, the U.K., and the U.S. chose not to intervene in free markets, and as a result experienced relative stagnation in some sectors of their economies. The French government did intervene, but focused intervention on the government managed, large scale French industrial enterprises. The medium sized and smaller French firms were left alone not only from government intervention, but also from meaningful assistance. As a result of this, the French domestic market remained weak. This in turn precluded the large government managed firms from developing a sufficiently large domestic market base to benefit from scale economies in the international markets. Conversely, the Japanese Government

(Chapter 12) enacted comprehensive government policies that significantly affected free market functions, established domestic and international markets and reaped significant benefits in terms of increased domestic production and an increased share of the world market for certain products.

FOOTNOTES TO CHAPTER 3

1. A number of recent studies have emphasized the need for advancement of science as a prerequisite for a nation's economic growth. See, for example: Ralph Landan and Netham Rusenberg, The Positive Sum Strategy: Harnessing Technology for Economic Growth, National Academy Press, Washington, DC, 1986; and Angus Maddison, "Growth and Slowdown in Advanced Capitalistic Economies: Techniques of Quantitative Assessment," The Journal of Economic Literature, Vol. 25, No. 2, June 1987, pp. 649-698.

2. Advanced technology products are defined by the U.S. Department of Commerce definition DOC3, which is based on R&D expenditures as a percentage of shipments. SIC categories included in this definition are: industrial inorganic chemicals (281); plastic materials and synthetic resins, synthetic rubber, synthetic and other man-made fibres, except glass (282); drugs (283); ordnance and accessories, except vehicles and guided missiles (348); engines and turbines (351); office, computing and accounting machines (357); radio and television receiving equipment, except communication types (365); communication equipment (366); electronic components and accessories (367); aircraft and parts (372); guided missiles and space vehicles and parts (376); measuring, analyzing, and controlling instruments, photographic, medical and optical goods, watches and clocks (38) -- except instruments for measuring and testing of electricity and electrical signals (3825). Source: U.S. Department of Commerce, United States Trade Performance in 1984 and Outlook, 1985-86 trade data supplied by Department of Commerce.

3. OECD defines Advanced Technical Industries as those for which R&D expenditures exceed 2.36 percent of value added. Using this definition, the tabulation below shows world export shares of advanced technology products for the five selected nations, during the 1965 to 1987 period.

	USA	FRANCE	GERMANY	UNITED KINGDOM	JAPAN
1965	27.5	7.3	16.9	12.0	7.2
1970	27.0	7.1	16.8	9.8	10.9
1975	24.5	8.4	16.8	9.6	11.6
1980	22.9	8.3	16.3	10.8	14.3
1985	24.2	7.9	14.8	9.2	19.4
1987	23.1	7.3	14.7	9.1	20.2

4. See, for example the comprehensive analyses on this in: Dale Jorgenson, et al., Productivity and U.S. Economic Growth, Harvard University Press, Cambridge, MA, 1987.

5. The historical 1980 to 1985 data in this section are based on the following studies: Ivars Gutmanis, U.S. High-Technology Trade Patterns 1980 - 1985, prepared for the Japan Electronics Bureau, Sterling Hobe Corporation, Washington, DC, 1985; and William F. Finan, et al., The U.S. Trade Position in High-Technology: 1980 - 1986, prepared for the Joint Economic Committee of the United States Congress, Quick, Finan and Associates, Inc., Washington, DC, 1986.

6. Electronics trade is defined as a subset of high-technology trade and includes: SIC 3573, 367, 3661, 3662, 3574, 3579, 38612, 386147, 3693, 3811, 3822, 3823, 3824, 3825, 3829, 3832. Source: U.S. Department of Commerce.

7. Spencer and Brander (1983) identify a total of seven "characteristics" of those industries which deserve government intervention or policies in order to achieve growth for these industries in domestic and international markets.

"<u>Characteristic 1</u>: The industry or potential industry must be expected to earn additional returns (expressed in profits or greater returns to workers) sufficient to exceed the total cost of the subsidy. This requires that at least for a period there be substantial barriers to entry."

"<u>Characteristic 2</u>: The domestic industry must be subject to serious foreign competition or potential competition. Subsidy of the domestic industry should lead foreign rival firms to cut back capacity plans and output. Although they are not necessary, large and inflexible capital requirements are likely to increase the chances of this type of behavior."

"<u>Characteristic 3</u>: The domestic industry involved in exporting should be more concentrated or equally as concentrated as the rival foreign industry."

"<u>Characteristic 4</u>: Factor prices should not increase much in response to domestic targeting. This is more likely if:

i. the industry does not have a strong union;

ii. worker incomes are at least partly based on profit sharing;

iii. no key input is in fixed supply."

"<u>Characteristic 5</u>: Targeting is more effective if:

i. the domestic industry has a fundamental cost advantage relative to the foreign competition;

ii. there are substantial scale or learning economies from increased production."

"<u>Characteristic 6</u>: A domestic industry will be a better candidate for targeting by R&D subsidies if:

i. there is a minimum of spillover of new domestic technology to rival foreign firms;

ii. the government intervention aids the transfer of foreign technology to domestic firms."

and

"<u>Characteristic 7</u>: If a domestic industry is involved in rivalry with foreign firms, it wil be a better candidate for targeting by R&D investment subsidies if:

i. R&D and capital costs form a significant proportion of industry costs, indicating they are important factors in firm rivalry;

ii. a likely winning product is in the early stage of development or production and R&D, and capital subsidies will raise entry barriers to foreign firms."

CHAPTER 4:

GOVERNMENT SCIENCE AND TECHNOLOGY POLICIES: TYPES AND CONTENTS

4.1 INTRODUCTION

Chapter 2 provided a brief comparative assessment of the science and technology activities undertaken in France, Germany, the U.K., the U.S., and Japan. The results of this analysis indicate that the magnitude and intensity of the activities related to science and technology (such as research and development, and employment of technical personnel) in the five countries are similar when adjustments are made for the size of the economies in each nation. In spite of the relatively comparable science and technology activities in the five nations, the economic growth in general, and the progress of advanced technology sectors in particular, has been anything but comparable.

In Japan, the dramatic increases in the production of advanced technology products has been unprecedented, and Japan has become the leading producer and exporter of a number of advanced technology goods. For example, in the early 1980's in the production and exports of microelectronic products, Japan overtook the U.S., who had been the world's leader in micro-electronics since the beginning of this important industry in the early 1960's. Production and trade statistics also show that the three European nations (France, Germany and the U.K.) are far behind in the production of advanced technology products, and that their markets in these products have been reduced by Japanese exports, in the world markets as well as within their national boundaries.

One of the principal assumptions of this thesis is that France, Germany, the U.K., and the U.S. have, in the past and continue at present, to conduct their economic, science, and technology policies in accordance with the prescriptions of classical economic theory; namely, very limited intervention in the economic functions by government policies. Conversely, the Japanese Government has intervened in economic, science, and technology activities with a comprehensive set of government policies and regulations. Such policies and regulations violate most of the basic prescriptions for economic growth and welfare contained in the classical economic theory. Such policies are recognized as appropriate for economic growth in a country by the economic policy prescriptions contained and sanctioned in the "new" economic theory. This Chapter examines more closely the concepts of science and technology as these are related to government policies, and analyzes the role of public policy in the development of science and advanced technology sectors.

4.2 THE CONCEPTS OF SCIENCE AND TECHNOLOGY IN THE CONTEXT OF GOVERNMENT POLICIES

Throughout the previous chapters, the terms science and technology were used without differentation with respect to government policies. Clearly, science and technology policies differ, and appropriate differences between these two policies are recognized in this Chapter.

From the perspective of public policy, scientific and technological activities may be analyzed as a joint product in the economic sense, i.e. these policies result in activities which need not be separated. These issues, however, require further exploration and discussion. Such exploration, in turn, can best be provided by setting forth the common characteristics of science and technology activities as well as the attributes of science and of technology which differ markedly.

One of the principal characteristics common to both scientific and technological activities is that both represent non-price competition. This notion was first advocated by Schumpeter (1934) and recently elaborated by Dasgupta and Stiglitz (1980). Another principle common to both activities is that both result in information or knowledge.

However, while both scientific and technological activities result in information, there are considerable differences in the type of information these two activities produce. Dasgupta and Stiglitz (1980) explain these differences as follows:

> We argued that science, as a social organization, views knowledge as a public consumption good, while technology regards it as a private capital good. Their collective attitudes being different, their norms and codes of conduct are different. An important feature of the 'scientific ethos' is that scientists are obliged to disclose all new findings and submit them for critical inspection by other members of the community. In submitting their findings to their peer group scientists, quo scientists, surrender claim to exclusive control of that information. In fact, the social norm is uncompromising: complete disclosure is the rule.
>
> In technology, as one would expect, the community rules are quite different. Disclosure is not the order of the day, reticence, and on occasion downright secrecy, is; for members of the community of technologists are motivated by the privately capturable rents that can be earned from their findings. One may then draw a sharp distinction between science and technology in regard to the disposition of their respective research findings and express it in the form of a social imperative; if one joins the science community one's discoveries must be disclosed completely, whereas if one joins the technology community such findings must not be fully revealed to the rest of the membership.

Another difference between scientific and technological activities is that scientific activity results are, in economic terms, pure public goods (Rosenberg, 1988).

Scientific activities are closely tied to technological activities, and often form a unified, but two phase undertaking. In order to foster technological advances, a policy maker may be required to encourage scientific activities.

As noted above, in the long run the funding of scientific activities depends on the monies received by industry for its products and services, which in turn depends on the profitability and level of sales by the industry, impacted by the level and advances of technology used by the industry.

It is not only the industries' profitability in monetary terms which has an impact on the level of activities in science, but also the national consensus on the need to select areas of science and industrial priorities which lead to improved industrial performance and therefore improved income, profits, and national welfare.

The critical role of the selection of scientific and technological areas for priority emphasis has been identified by many scholars. Most recent emphasis has been placed on this issue by a OECD report, Science and Policy Outlook, (OECD, 1988) which reports that the failure to increase output in several key areas, despite several years of priority attention, suggests that there may be "serious flaws" in the public policy mechanisms many OECD countries use to allocate resources.

From the public policy perspective, therefore, scientific and technological activities may be considered as the same.

4.2.1 Expanding Geographic Dimensions of Science and Technology Activities

The enlargement of spatial dimensions in the activities of science and technology in recent years will be discussed and pointed out in Chapter 5. Clearly the spread of scientific activities and diffusion of technology across geographic areas has accelerated.

Even a cursory reading of the bibliography on these issues suggests that many of the principal studies on the international dimensions of science and technology activities are relatively recent, with the bulk of these published after the 1960s. However, the recognition of certain international dimensions of science and technology activities dates back to the mid-18th Century, as presented by David Hume in 1758, and Hume's predecessor Reverend Josiah Tucker.

> . . . it may be laid down as a general Proposition, which very seldom fails, That operose or complicated Manufactures are cheapest in rich Countries; -- and raw Materials in poor ones . . . No Man can set Bounds to Improvements even in Imagination; and therefore, we may still be allowed to assert, that the richer manufacturing Nation will maintain its Superiority over the poorer one, notwithstanding this latter may be likewise advancing towards Perfection (Reverend Josia Tucker, 1658; as quoted in Hufbauer, 1970).

Hume's and Tucker's works appeared some twenty years before Adam Smith's celebrated theory of the division of labour, and sixty years before Ricardo's theory of comparative advantage.

Clearly, geographic aspects of scientific, technological and related activities have been observed and noted for over two hundred years.

Systematic and continuous analyses of the international dimensions of these issues, however, only began in the 1960's. The analyses by Posner (1961) and Vernon (1974) contained some of the pioneering work in this area. Posner postulated a technology gap among nations, and implicitly agreed with Rev. Tucker's argument that one innovation leads to another and that technology gaps may be self-perpetuating.

According to Vernon (1974):

> Although primary scientific knowledge is an international public good, the entrepreneurial application of such knowledge requires a local stimulus because it is easier to gather information on latent demand the nearer one is to the potential market. Thus, that country in the world which has the highest per capita income will be the first to satisfy the latent demand for new consumer goods.

Technology transfer across national boundaries has been subject to recent analysis by Mansfield and Romeo (1980) and Mansfield, Romeo and Wager (1979).

Building on the assumption of a leading country having a comparative advantage in innovation, Connolly and Hirschey (1984) and Pugel (1982) have investigated costly innovation and optimal licensing policy. In these general equilibrium models, labour in the leading country can be freely transferred between production and R&D activity. Finally, Pavitt (1980) describes technological leadership as a particular type of national trust, specifically comparative advantage in innovation.

Throughout these analyses it was recognized that the spatial distances between nations are radically shrinking because of technological advances in transportation and changes in national policies exemplified by the growing influence of multinational corporations, co-production agreements, and the exchange of patents (Jones, 1970; Krugman, 1979; Spencer and Brander, 1983).

Advances in transportation services, principally air transport, has enabled certain commodities to be transported across continents at very inexpensive relative costs. The extent of air transport services used in the shipment of certain products across national boundaries can be readily seen from the information presented in Table 4.1. The information identifies the modes of manufacture of a certain microprocessor developed and marketed by Intel Corporation. As can readily be seen, a total of five separate manufacturing operations comprise the production of this microprocessor in a total of four nations. The total distance covered in the transport of this microprocessor is over 28,000 miles.

TABLE 4.1

Sequence and Location of Microprocessor Production in Intel Corporation

Manufacturing Mode/ Geographic Areas	Manufacturing Activity
United States of America	Design and Manufacture of Masks for Microprocessor Components
Israel	Manufacture of Microprocessor Components
Malaysia	Testing of Components
Mexico	Bonding of Components
United States of America	Final Packaging/Sales

Source: SHC, 1988.

Advances in air transport have also led to a very substantial reduction in costs. It has been estimated that the cost of transporting the microprocessor represents less than two percent of the selling price. Such flexibility to select modes of manufactures has provided the management of industrial firms with a number of management options, and at the same time, has placed demands on public policy to take measures in a nation's interests.

The growth of multinational corporations and other international arrangements on the use of the results of science and technology development have also provided the management of industrial enterprises with a number of options not available to management when national boundaries were enforced more strictly. These options include choices of manufacturing locations, market area and services of capital. These opportunities available to the managers of industrial firms have, in turn, produced public policies, enacted and exercised to protect the nations' (i.e., public's) self-interests.

The shrinking geographic dimensions of science, technology, manufacture, and sales of products have, on the one hand, provided options for the private sector to locate off-shore and, on the other, have resulted in the emergence of public policies designed to protect national boundaries.

4.2.2 Topology of Government's Science and Technology Policies

One of the reasons for a government to intervene in the conduct of science and technology is to preclude duplication of these activities. Another reason is to ensure that certain societal goals are accomplished, even if such accomplishment results in smaller returns to the private sector than some other goods.

Such government intervention may be considered normative as it is dictated by welfare considerations for society. As noted in Chapter 2, such government policies are also "allowed" within the context of the theory of political economy. These types of government policies are of secondary interest in this thesis.

The focus of the analysis presented in this chapter is on government policies which attempt to establish competitive advantage for a nation in certain economic sectors in order ultimately to gain economic benefits from international trade in the goods and/or services produced by these sectors.

The emphasis of such government policies is on the technological rather than the scientific activities. There are several reasons for this. Scientific activities result in knowledge or information that is, as already noted, a "public good". Public good represents a commodity (such as a patent) which is available to many potential users and the use of which does not diminish or reduce the original value of the commodity.

Regulation of such public goods is difficult to accomplish without very severe and restrictive government policies (for example, the U.S. Atomic Energy Commission policies regarding nuclear processing plants). The results of scientific activities may be transferred to other parties and other nations with relative ease because results of scientific activities (such as patents) may be summarized in a format very convenient for transfer.

It has also been argued that successful scientific activities require the free exchange of scientific ideas and concepts among the scientific community, not only within a nation, but also on an international level. Significant government intervention in scientific activities, therefore may be counterproductive.

The above does not suggest that governments do not enact policies which impact on scientific activities within a nation. On the contrary, governments do indeed enact such policies. However, government intervention in activities which lead to technology advancement and development are much more frequent and the specific government policies much more comprehensive. There are two reasons for the policy emphasis on technology rather than science. Information or technology development is, as a rule, specific, detailed, and comprehensive. Transfer of such information is difficult and time consuming, and control of such transfer by government policies may be accomplished more readily.

The second reason for government emphasis on technology policies is that advanced technology development and utilization may lead directly and immediately to increased sales (domestic and international) of products with embody these advanced technologies. Payoffs from scientific activities take considerably longer.

The specific policies enacted for the scientific and the technological advancement of a nation are dependent, of course, on the institutions, laws, regulations, etc. of the specific nation. Therefore, public policies, but not the objective of such policies, may differ significantly among countries.

Table 4.2 presents a summary of common public policies which a government may enact to advance domestic science and technology activities. The purpose of these policies is to shield domestic firms from foreign imports, and to defy the dictates of shifting comparative advantage.

Restraints on foreign investment tariffs, quotas, import restrictions, discriminatory government procurement, and voluntary restraints are the principal policy instruments. Home market

TABLE 4.2

Common Government Policies for Advancement of Science and Technology by Major Category and Techniques

CATEGORY	TECHNIQUES
Home-market Protection	Restraints on foreign investment
	Tariffs
	Quotas Import restrictions
	Discriminatory government procurement
	Voluntary restraints
Tax Policies	Accelerated Investment tax credit depreciation rules
	Credits for R&D
	Exemption for export earnings
	Tax deferral for export earnings
	Grants
Antitrust Exemptions	Mergers
	Price fixing cartels[1]
	Rationalization cartels[2]
	Export cartels[3]
	Joint research and development
	Restrictions against competition
Science and Technology Assistance	Support for R&D
	Control over technology imports
	Requiring technology sharing as a condition for exporting to, or investing in the country (performance requirements)
	Assistance in acquiring foreign technology
	Training
Financial Assistance	Loans at preferential rates
	Loan guarantees
	Export financing
	Preferential access to investment funds
	Preferential access to foreign exchange
	Nationalization

[1]Price-fixing cartels involve agreements concerning prices the firms charge in the domestic market.

[2]Rationalization cartels involve agreements concerning the product lines firms will produce or the facilities they will operate.

[3]Export cartels involve agreements concerning export markets.
Source: SHC, 1988.

protection places foreign firms at a competitive disadvantage in the domestic market.

Voluntary restraint agreements. The United States has imposed such agreements on textiles, apparel, colour television receivers, footwear, steel, and automobiles.

Standards and other non-tariff barriers. These consist of health, safety, or environmental standards. Other non-tariff barriers consist of approval and settlement systems, customs practices, application of standards, and explicit trade subsidies to specific industries.

There are five major types of policies which result in the tax benefits:

a) **Investment tax credits.** For example, until 1982, U.S. law provided a 10 percent tax grant for the acquisition for machinery and equipment.

b) **Accelerated depreciation.**

c) **Credits for research and development.**

d) **Tax deferral for export earnings.** For example, under U.S. law, Domestic International Sales Corporations (DISCs) are exporters' subsidiaries entitled to hold a percentage of their export earnings without being taxed until the earnings are formally attributed to the parent company. Nearly half of U.S.

merchandise exports pass through DISCs, which in 1987 resulted in exporters receiving interest-free loans of $182 billion.

e) **Grants.** Antitrust exemptions allow firms in an industry to take joint actions that would be illegal if undertaken by most firms. Examples of these joint actions include mergers, joint research and development, and agreements to fix prices, allocate market share, and assign products.

Antitrust exemptions may increase the international competitiveness of domestic firms by reducing their costs. Mergers may allow firms to realize increasing economies of scale. For example, the Japanese government has often encouraged firms to merge so they could reduce costs by increasing the size of their plants. Also, the Japanese government has occasionally allowed firms in an industry to agree to limit the number of different products each firm produces. By limiting their product lines, firms may be able to reduce the unit costs of their remaining products.

The Japanese government frequently allows industries to form export cartels. Firms in an industry usually form an export cartel solely to raise prices charged to foreign purchasers. To increase its prices, the cartel typically reduces shipments to foreign markets. A cartel might take this action primarily to increase its profits on export sales or to avoid having a foreign government impose import restraints (SHC, 1988).

Governments provide a competitive advantage by subsidizing their research and development efforts. This research and development may be conducted by the government itself, by private researchers, or jointly by the two. For example, the Japanese government joined with five Japanese semiconductor firms and NIT in the Very Large-Scale Integration (VLSI) Development Association. This association funded and coordinated most of the VLSI research. The U.S. government provided similar assistance to the U.S. microelectronic industry during the 1960's (SHC, 1988).

Science and technology policies often involve acquiring technology from abroad. For example, the Japanese government during the 1954 to 1962 period, supervised all agreements for Japanese firms to import foreign technology. It has been stated that this policy was enacted to use government policy power to obtain more favourable terms from foreign firms than its technology-importing industries could have obtained on their own (Yano Research Institute, 1983).

Governments sometimes do not allow foreign firms to sell to, or invest in, their country unless they share their technology with domestic firms. The Republic of Korea, for example, requires foreign firms to share technology as a condition for selling computers in that country. Government expenditures for training (eduction) such as Japanese policies, represent another type of policy (SHC, 1988).

The number of government policies to provide various kinds of financial assistance is very large. These include: subsidies, bailouts, temporary import restraints, government procurements, facilitation of investments and exports, protection against foreign price competition via trigger price mechanisms, relaxation of regulation requirements, tax relief, R&D incentives, capital formation facilitation, guarantees of fair foreign competition, guarantees against technological theft, foreign exchange rate intervention, and elimination of foreign trade barriers.

These public policy techniques increase the access of firms to public monies, investment funds, or to foreign exchange. They also enable firms to alter investment funds or foreign exchange at better terms than would otherwise have been possible. For example, the government can provide loans to firms below market interest rates, as Japan has done through the Japan Development Bank, to domestic producers in target industries.

Instead of actually lending money to firms, the government might guarantee repayment to the firms' private lenders. Government loan guarantees can substantially reduce the interest rate that a firm pays on a loan by protecting the lender against default (Kealy, 1987).

Governments also sometimes assist in financing foreign purchases of exports of targeted industries. By financing these exports at below-market interest rates, a government may provide domestic producers with a significant competitive advantage. Most industrialized nations have export-financing facilities that provide both direct loans and loan guarantees. Export financing, however, is targeting only if exports of certain industries are given preferential treatment.

Financial assistance can be provided by guaranteeing a firm's access to credit or foreign exchange. Governments sometimes intervene in their domestic financial markets to reduce interest rates artificially. The government can guarantee access to foreign exchange to producers in selected industry sectors. The ability to control the supply of foreign exchange available to firms played an important role in Japan's industrial policy during the 1960's and 1970's. In 1971 the U.S. provided $250 million in loan guarantees to the Lockheed Corporation, and, in 1980, $1.5 billion to the Chrysler Corporation (SHC, 1988).

As can readily be seen, the types and kinds of government policies available to advance scientific and technological programmes either directly, or by advancing sections of the economy, are many. The use of these policies and their variants are presented in the subsequent sections of this chapter.

4.3 GOVERNMENT POLICIES TO ADVANCE SCIENCE AND TECHNOLOGY

This section provides a brief examination of the role of public policy in the development of science, advanced technology, and those sectors of the economy which embody advanced technologies as an introduction to Chapters 8 to 12. This preliminary examination is provided to set the stage for the analyses of the three advanced technology sectors (microelectronics, machine tools, and advanced materials) presented in Chapters 5 to 7.

The performance of the U.S. in advanced technology products has declined, and yet, because of its historical dominance in advanced technologies, the U.S. remains a major force in the world's marketplace. The trends in advanced technology products for Germany are mixed. Some advanced technology sectors, such as machine tools, have advanced. Others, such as microelectronics, have been stagnant. For the U.K. and France, the growth in advanced technology products has been marginal. Japan has shown more growth, in terms of any measure, than the other four nations.

Conversely, the science and technology indicators for these five nations, indicators which illustrate the inputs to science and technology activities (such as R&D expenditures and engineers or scientists entering the labour force) show relatively stable patterns for all five nations. As presented in Chapter 2, all five nations have expanded inputs in their nation's science and technology activities, but the pattern of such inputs, in terms of inter-country comparison, has remained stable during the last twenty years.

In the light of the above, it may be suggested that it is the differences in government science and technology policies which are, at least partly, responsible for the differences in the performance of advanced technology sectors.

The differences in the science and technology policies among the five nations are indeed significant, as is shown in this chapter. To an important extent, these differences result from a nation's willingness to guide, to a larger or smaller degree, its market economy via rules, regulations, restrictions, encouragement, etc. Guidance, of any sort, of a nation's market economy breaks the cardinal rule of classical economics.

As noted in Chapter 3, according to classical economic theory non-interference in domestic markets by government policies results in optimum economic progress and societal well-being for any nation. In the case of international trade, non-interference in world markets by government policies results in the world trade of goods and services being dictated by comparative advantage in the production of goods and rendering of services. Here again, classical economic theory predicts that such international trade built on the basis of comparative advantage will yield optimum societal benefits to all nations participating in such trade.

Yet, the empirical results with regard to international trade presented in Chapter 3, show that Japan, which has violated the non-interference rule of classical economics in domestic and foreign trade, has instead prospered, and perhaps prospered at the expense of other nations. Japanese success in world markets for microelectronics and advanced machine tools represents a good example of this. On the other hand, French governmental policies, which have also explicitly broken the rules of classical economic theories, have little to show for their intrusion in the free market economy (Cline, 1983).

The policies of the U.S. government, with regard to advanced technology adaptation and industry sector development, have for the most part (but not to the extent proclaimed by some) honoured the free market system. Even so, the growth of the micro-electronics industry in the United States has been phenomenal, and the U.S. continues to dominate the world in microelectronic products, although the Japanese have been able to accelerate the growth of their own microelectronic industry in the world market since 1980 (Zysman, 1983).

Germany has practised essentially a policy of non-intervention in the development and growth of these advanced technology industries, and therefore may represent the opposite role from Japan. Yet, the German advanced machine tool industry is one of the principals in the world market.

This implies that there may exist several routes to the advancement of technology and advanced technology sectors. As presented in the following section of this chapter, an ingredient necessary for the advancement of technologies is advancement in science. Prior to the 1960's, the advancement of science in a nation was, more or less, a national phenomena, stopping at a nation's geographic boundary. However, advancements in science since the 1960's need not adhere to the geographic boundaries of a nation.

The rapidly increasing international communications system allows for information exchange across national boundaries with increasing ease and speed, and allows for a nation to obtain and apply scientific information originating in other nations.

Two factors account for the rapid increases in the international communications system. The first of these consists of the technological advances in communications, travel, and transport. The other pertains to the interutilization of locations of economic activities brought about by multinational corporations, off-shore facilities, and joint ventures of all types.

It remains of some importance for a nation which attempts to foster its technologies and develop industry sectors which are based on scientific advances, to possess strong and viable science activities.

The crucial question here appears to be that of timing and sequence of government policies directed towards fostering scientific activities as compared to policies which assist the development of advanced technology industry sectors. Increases in scientific activities and the development of advanced technology industries require significant expenditures, either by government in the use of public monies, or by the private sector in the use of proceeds from sales. Expenditures (public or private) for the advancement of science in any country cannot be sustained over a period of time without the fruits of such expenditures, in terms of increased sales from advanced technology products, produced on the basis of scientific knowledge.

Japanese scientific and technology policies have been implemented with a full understanding of this fact. During the 1960's and 1970's, the Japanese government had only limited science policies and provided equally limited financial assistance for scientific research. Scientific activities by the Japanese private sector during this period was also limited.

During this same period, the Japanese government issued and enforced comprehensive policies and provided significant financial assistance in the development of advanced technology industry sectors (i.e., so-called targeted sectors). The technology used in these sectors was that developed by the U.S., the U.K., Germany, France, and other nations.

The growth of international communication systems allowed Japanese firms to acquire the needed technological base. Japanese sales of advanced technology products soared in Japan and in international markets. These commercial successes provided the Japanese government and the private sector with the means to encourage actively scientific activity in Japan, and starting in 1980, the Japanese government adopted extensive policies, accompanied by financial assistance, to undertake a series of comprehensive and long range scientific activities (U.S. ITC, 1986).

Scientific activities in the U.K. have been pursued throughout its history with exceptional vigour, and have resulted in many important scientific developments. Conversely, technological advances in U.K. industry sectors have been modest with equally modest sales in the world market for advanced technology products. The governments of the U.K. have enacted limited policies for both the advancement of science and the development of advanced technology sectors (SHC, 1988).

In France, scientific activities have often been directed by very explicit government policies. French advanced industry sectors controlled by the French government have also from time to time been explicitly directed by the government. The French government enacted science and industry policies which would encourage scientific activities and the growth of advanced technology industries, but prescribed these in some detail and did so without an attempt to reach consensus with industry. Simply put, governmental policies not only violated the rules of classical economics, but paid no attention to the views of French industrial entities that were not controlled by the government. The results of French policies have been mediocre (Zuscovitch, 1985).

German goverments have enacted few science and industry development policies during the last decade. Industry sectors which have been historically well developed in Germany, with significant domestic and international sales (such as machine tools) have prospered. New advanced industry sectors (such as microelectronics) have not done well, except in those cases were German firms formed joint international ventures (SHC, 1988).

In the U.S., the government provided guidance and financial support for scientific activities to a more significant extent that is usually recognized. The U.S. government policies and financial assistance to the development of advanced industry sector were insignificant.

U.S. scientists made a number of important scientific advances, and many of these were utilized by advanced industry sectors. The absence of government policies and financial support to advanced industry sectors, however, has resulted in the inability of the private sector to acquire and install advanced production technologies, and United States industry has lost a significant proportion of the world market to the Japanese, NICs and other nations (ITC, 1986).

In Chapter 3, the trends in international trade among the five nations were analyzed, and important changes over time for some nations were indicated. In the case of the U.S., the absolute surpluses in foreign trade for all commodities, for merchandise, and for advanced technology goods changed in the early 1980's. This change was manifested first in the decline of U.S. exports, followed by a more or less neutral trade balance, and then from 1984, a rapidly increasing negative trade balance for all types of advanced technology products. This trend continued in 1988. As of July 1989, the U.S. trade deficit was estimated at $81 billion, in spite of a gradual increase in exports (total exports in 1989 were estimated at $311 billion, as compared to $221 billion in 1987).

Japan has experienced the largest increase in its balance of trade in the 1980's, and has become one of the world leaders in advanced technology exports. Germany has also significantly improved its balance of trade in the 1980's, and in 1987 was the world's largest exporter of advanced technology products. The U.K. and France have experienced relative stability in their balance of trade of advanced technology goods during the 1980's.

As shown in Chapter 2, in terms of absolute and relative comparisons, the resources devoted to science and technology among the five nations have remained relatively stable during the 1980's. There exists, for example, no evidence in these data which would allow a relationship to be established between the decline of advanced technology exports for the United States and the increase in such exports for Japan.

Likewise, the growth of Germany's exports of advanced technology goods cannot be explained by increases in German scientific and technical activities. These have remained relatively stable during the period when German exports of advanced technology products have increased substantially.

The classical economic theory on the comparative advantage of one nation as compared to others, and therefore the ability of this nation to increase its world market share of products, as presented in Chapters 2 and 3, provides little, if any, explanation as to why Germany or Japan would be able to increase its exports of advanced technology products, whereas such exports from the U.S. would decline.

As presented in Chapter 3, the so called factor endowment in the classical economic sector (in the case of advanced technology products, the scientific and technological activities which yield advanced technology goods) is the key determinant of a nation's comparative advantage.

The information provided in Chapters 2 and 3 do not suggest that either Japan or Germany has achieved, during the last decade or so, particularly significant improvements in the factor endowment; nor does the information suggest that in the U.S. the factors of production have diminished in quality or quantity. Yet the international trade statistics indicate a considerable weakening of the U.S. trade position in all commodities, including advanced technology products.

Casting the classical international economic theory aside, a number of economists in the U.K., the U.S., Germany, and elsewhere, have begun to construct a new international trade theory which supports the international trade statistics. These economists, lead by Krugman (1984), Pavitt (1987), and others, have disregarded some of the economic concepts used by classical economists and have placed emphasis on other sets of variables in their development of an international trade theory. Among the new variables introduced, government policies are of cardinal importance.

This represents a radical change in economic theory, and one that has very important consequences. This results from the fact that government policy is not an economic or geographic variable like, for example, Ricardo's postulation of geographic factors. Government policies represent deliberate actions to interfere with free market economics. Interference with free markets was considered under classical economic theory, but only to point out that any such action via public policy, or by any other means, would result in diminished economic well-being for that nation.

This clearly has not happened in the case of Japan, where government policies are used with some frequency to interfere with free markets, and have resulted in significant improvements in Japan's economic well-being. Chapters 8 to 12 analyze these governmental policies in detail, in particular as these have been applied to the three advanced technology sectors. The following chapters (5, 6 and 7) present analyses of these three advanced technology sectors for each of the five countries.

4.4 SUMMARY

There exists a relatively large number of specific policies that a government may utilize to advance a nation's economy in terms of domestic production, but especially to increase exports and therefore gain a larger world market share.

Contrary to classical economic prescripts, over the last several decades Japan has enacted policies that intervene with free market functions, and has succeeded in establishing its advanced technology industries as leaders in the world markets. Germany, the U.S., and the U.K. have enacted very few policies that disrupt free market activities, and as a result have lost significant portions of their export sales (as in the U.S.) or have been able to increase the output of the advanced technology sectors only to a marginal extent (as in the case of the U.K.). In France, over the last two decades, the government has enacted polices designed explicitly to assist the French advanced technology sectors with very poor results.

As stated in Chapter 1, the general aim of this thesis is to determine government policies that result in production and export increases for a country. Given the analysis presented in Chapters 2 and 3, this overall aim may be elaborated by adding the following objectives of the research undertaken for the three advanced technology sectors in the five countries:

a) determine relevant government policies to increase production of advanced technology sectors;

b) determine relevant characteristics of a nation's infrastructure that foster government intervention in the market economy; and

c) examine the interrelationship between the development of advanced technology sectors and characteristics of government policies.

CHAPTER 5:

INTERNATIONAL ACTIVITIES IN THE MICROELECTRONICS INDUSTRY

5.1 INTRODUCTION

The growth of the world microelectronics industry is virtually without precedent in the annals of modern industry. Since 1967 -- when the integrated circuit was developed -- the worldwide output of this industry has increased dramatically. In 1967 the total output of microelectronics devices was valued at slightly less than $2.3 billion; in 1988 that output was estimated to be over $47 billion (SHC, 1987). These large increases are not only expected to continue, they are projected to accelerate in the future, and in 1995 reach worldwide sales of over $130 billion (SIA, annual report, 1987).

The world microelectronics industry exhibits characteristics of a highly dynamic industry which bears little resemblance in structure and markets to mature technology industries such as steel, non-ferrous metal processing, or textiles (Mowery, 1983). The dynamic nature of this industry translates into a number of unique attributes, such as (a) the international/multinational scope; (b) the fact that many firms undertake cooperative research and manufacture of microelectronic products across national boundaries; (c) the emergence of numerous new product lines and applications; (d) very rapid technological advance; and (e) the continuous international diffusion of technologies. Indeed the world industry has evolved into a complex and dynamic structure with large mutual benefits to all participants (SHC, 1988). The principal reason for the accelerating manufacture of microelectronic devices is their expanding use in a wide range of consumer and industrial products.

Table 5.1 demonstrates the wide spectrum of microelectronic device applications. Moreover, the requirements for microelectronic technology are becoming paramount in every industrial society. This point is echoed in a study by the Semiconductor Industry Association (SIA), which states:

> There is virtually no new product today which is not affected by semiconductors. Some are so commonplace that we take their existence for granted; others are truly awe-inspiring.
>
> Military applications are especially tied to the advances in performance which have occurred in microelectronics. Applications range from reconnaissance satellite sensors to battlefield communications systems, from "smart" bomb guidance systems to sophisticated electronic warfare equipment. Never before in the history of the United States have strategic military implications with regard to national security been more dependent on the design, manufacturing, and application of high technology integrated circuits as now.
>
> In commercial applications, semiconductor technology is taking on a strategic importance as it becomes a larger and larger component of complete electronics systems. Dominance in semiconductor technology is crucial to U.S. competitiveness in such major electronics-based industrial sectors as computers, telecommunications, industrial controls, and robots (SIA, 1983).

TABLE 5.1

Selected Microelectonic Device Applications by Sector 1988

SECTOR	APPLICATION
Consumer Goods	Household Domestic Appliances
	Entertainment Products
	Personal Products Cars
Computers and Peripherals	Minicomputers Memory Equipment Input/Output Equipment
	Data Transmission Equipment
Telecommunications	Exchange Equipment
	Transmission Equipment
	Subscriber Equipment
Office Equipment	Data Processing
	Word Processing
	Audio Equipment
Test, Measuring and Analytical Instruments	Test/Analytical Instruments
	Medical Equipment
	Automatic Test Equipment Nuclear Equipment
Industrial Control	Sequence Control
	Supervisory Control Systems
	Monitoring and Data Recording Systems
	Industrial Robots
State-Purchased Equipment	Military and Aerospace
	Education Systems Health Systems

Sources: OECD, 1984 revised, 1988.

5.2 WORLD MICROELECTRONIC MARKETS

Since 1967, when the significant commercial production of microelectronic components was initiated, the growth in worldwide production of microelectronic devices has been rapid, and is accelerating, accompanied by a growing internationalization of the industry. This is evident in increased exports and imports of microelectronics in the major producer and consumer nations, in a rise in the number of international investments, in international technological diffusion in the industry, and in increased international competition in the world microelectronic market.

As noted in the introduction to this chapter, the total value of worldwide microelectronic product shipments increased from $2.3 billion in 1967 to over $47 billion in 1988 (SHC, 1987). See Table 5.2. During this twenty year time period, the years 1967 to 1974 saw a real rate of increase of 238 percent, at an annual compounded growth of 19.0 percent. During the 1974 to 1988 period, the two respective figures were 167 percent and 8.3 percent. Projections based upon current trends suggest that shipments of microelectronic products will be above $130 billion by 1995 (SIA, annual report, 1987). If so, the annual compounded growth rate of worldwide microelectronic device shipments in this 23 year period, which essentially covers the industry from its inception, will be over 30 percent.

TABLE 5.2

Trends in Worldwide Microelectronic Device Shipments, 1976-1995 (in millions of current dollars)

YEAR	DOLLARS
1967	2,300
1970	3,146
1975	6,104
1979	1,424
1980	15,800
1985	24,808
1986	31,009
1987	38,430
1988	47,542
1990	53,816
1995	132,000

Source: SIA printouts for historical years, for 1990 and 1995 the source is the SIA Annual Report, 1987.

The principles of microelectronics devices were discovered in the U.S., and the U.S. dominated the world microelectronic industry until the mid-1980's. Japan, however, caught up with the U.S. in 1982 and currently represents the single most important microelectronic component producer, consumer, and seller in the international market. Other industrialized nations are more limited in microelectronics component production as well as consumption.

The increasing importance of the Japanese microelectronic industry in the past decade can be readily seen from Table 5.3. In 1978 Japan accounted for about 27 percent of the world consumption of microelectronic products. By 1988 Japan's share had increased to almost 37 percent. The U.S.' share declined from 39 percent to 31 percent over the same period. Microelectronic device consumption in Europe, as a proportion of worldwide consumption, declined even more during this period. In 1978 European nations consumed about 26 percent of the world's microelectronic device production, by 1988 this proportion had declined to 17 percent.

In 1988, the U.S. and Japan accounted for more than 68 percent of all microelectronic device shipments in the world. The data on international trade in microelectronic goods demonstrate, however, that there are significant exports as well as imports

TABLE 5.3

Microelectronic Product Consumption, by Geographic Region, 1978 and 1988 (in millions of current dollars)

COUNTRY OF ORIGIN	1978	1988
Worldwide	8,953	47,364
Total U.S.	3,506	14,924
Total Other	5,447	32,356
Europe	2,339	8,066
Japan	2,448	17,347
Other	660	6,943

Source: SIA Statistical Review, 1988.

among countries which manufacture and consume microelectronic products. While the majority of microelectronic products are consumed in areas in which they are produced, a significant proportion of microelectronic goods were shipped to other areas (Table 5.4). Several reasons account for this international trend.

The first is the fact that a large number of U.S. and Japanese companies, and to a much lesser degree those of other nations, have established overseas production facilities. There are no official recent data as to the number of such facilities established. Sterling Hobe Corporation reports (1982 and 1988) suggest that as of February 1988, over 631 facilities owned or partly owned by U.S. firms were operating outside the U.S. (Table 5.5).

The available information also indicates that as of early 1987, a total of 37 overseas microelectronic manufacturing facilities were established by Japanese firms (SHC, 1987).

The U.K., France and Germany followed this pattern, but to a much lesser degree. The U.K., for example, located a large microelectronic facility in the U.S. (the INMOS plant in Colorado Springs) and France established several facilities in the U.S., Israel and the Far East. Most of the initial off-shore microelectronic facilities established by the U.S. and Japan were located

TABLE 5.4

Exports and Imports of Microelectronic Products
for Selected Countries, 1987
(in millions of current dollars)

COUNTRY	EXPORTS	IMPORTS
United States	$3,472	$3,533
Japan	2,861	378
United Kingdom	38	615
France	211	967
Germany	314	892

Source: U.S. Department of Commerce Printout, 1988.

TABLE 5.5

U.S. Microelectronics Overseas Manufacturing Operations, by Year Established' 1955-1988

YEAR	TOTAL OPERATION
1955	1
1956	-
1957	1
1958	-
1959	1
1960	2
1961	1
1962	-
1963	3
1964	2
1965	2
1966	4
1967	4
1968	8
1969	27
1970	15
1971	10
1972	7
1973	18
1974	7
1975	76
1974-1980	219
1980-1986	201
Date Unknown	22
Total	631

Source: For the years 1955-1974: U.S. Department of Commerce, A Report on the U.S. Semi-Conductor Industry, 1979. For the years 1974-1988: Sterling Hobe Corporation, 1982 and 1988.

in NICs. This was due to cheap labour rates and the availability of the required industrial infrastructure.

This increasing internationalization of the microelectronic industry has been of considerable benefit to these newly industrialized countries which have gradually increased their own native microelectronics sectors, and have become a factor in world markets. The increases in microelectronic product manufacture in these nations have been exceptionally large (Table 5.6).

The trends toward the international diffusion of the microelectronics industry are expected to continue. It is projected that the relative output of microelectronic products of the U.S., Japan and European nations will decrease and that production by the NICs will increase (Figure 5.1).

An important factor which advances the international diffusion of the microelectronics industry is the increased effort by foreign governments to provide significant financial and other benefits to firms which locate microelectronic manufacturing facilities in their countries. Offers of financial assistance by foreign governments can be especially attractive to U.S. microelectronic product firms because of shortages of venture capital in the U.S. The U.S. microelectronic industry has in fact taken increased advantage of various capital subsidy schemes offered by foreign countries (Vernon, 1988-89). Moreover, manufacturing

TABLE 5.6

Recent Trends in Microelectronic Product Manufacture in Selected Newly Industrialized Countries, 1980 - 1988 (in millions of current dollars)

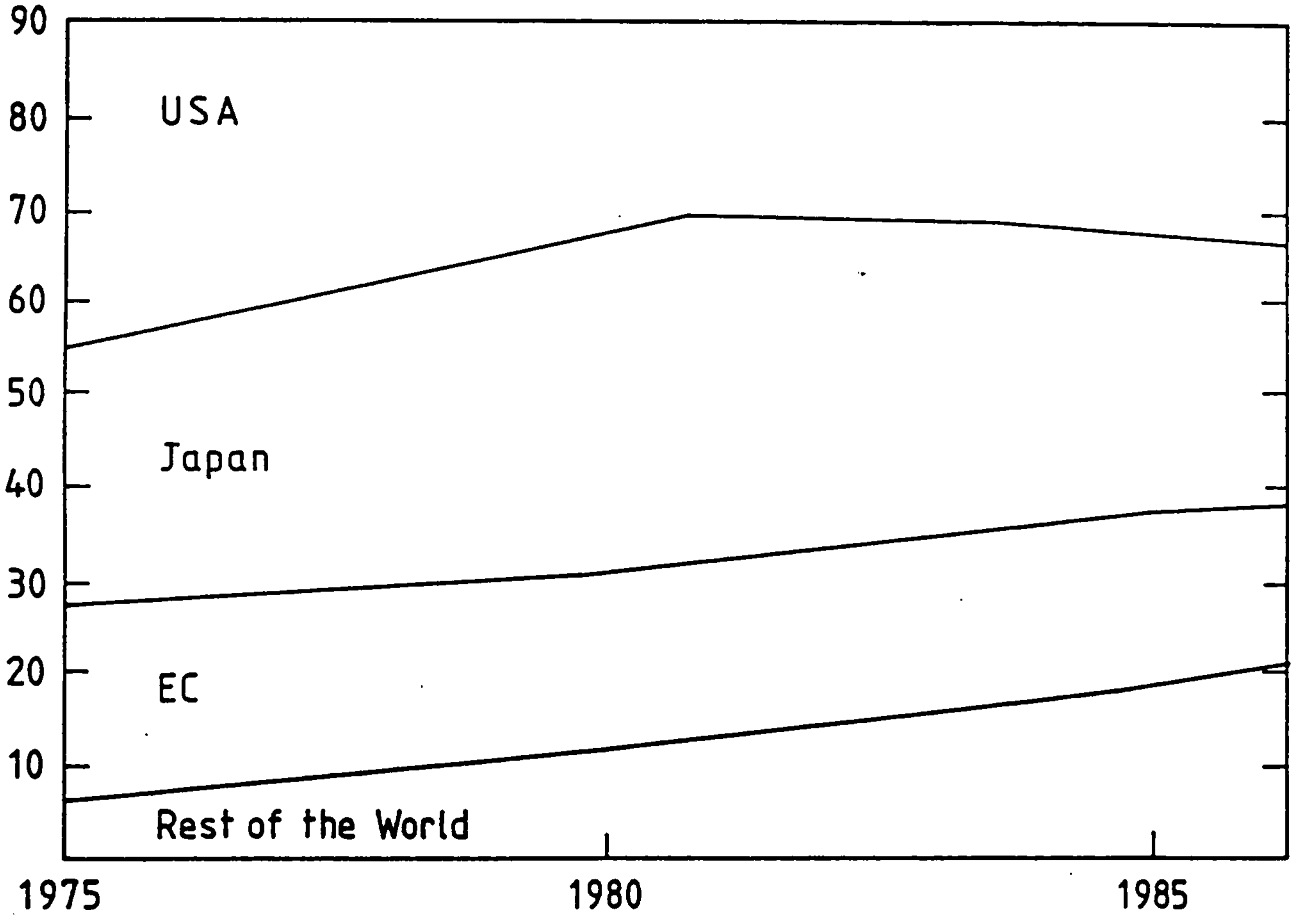
COUNTRY	1980	1985	1988
South Korea	$97	$225	$640
Taiwan	36	100	250
Hong Kong	27	110	190
Other[1]	23	95	170

[1] Includes: India, Brazil, Malasia, and Singapore.

Source: ICE, 1988.

Figure 5.1

Worldwide Microelectronics Market
by Major Geographic Area, 1975-1987
(in percent)



Source: STA Printouts, 1987.

capital requirements are rapidly increasing, rendering the need for additional capital more pronounced over time.

Another factor leading to the increasing international dimension of the microelectronic industry is the growth of international cross-licensing, co-production, or patent sales (Cheng, 1984; OECD, 1984).

The increasing dimensions of the international diffusion of the microelectronic industry can be readily seen from information as to the origin and destination of U.S. imports and exports of microelectronic devices for 1967, 1977, and 1987, which rank in dollar values the origin and destination of U.S. microprocessor products, imports, and exports (Tables 5.7 and 5.8).

As the information in Table 5.7 indicates, U.S. imports of microelectronic products have shifted to countries that enjoy low labour rates, such as Malaysia, Singapore, and the Philippines. These U.S. microelectronic device imports are, in fact, semi-finished microelectronic products manufactured in the low labour rate nations and imported by U.S. firms for final assembly. The dominance of Malaysia, Singapore and the Philippines as the destination of U.S. microelectronic product exports also reflect the large scale low labour rate manufacturing facilities in these countries. Essentially all of these exports are microelectronic components shipped to the countries for further manufacture and

TABLE 5.7

Origin of U.S. Imports of Microelectronic Devices 1967, 1977, and 1987 (in thousands of dollars)

IMPORTED FROM	RANK	1967	RANK	1977	RANK	1987
Malaysia	-	0	1	286,118	1	879,968
Singapore	-	0	2	257,360	2	593,037
Philippines	-	0	8	71,436	3	469,327
Japan	3	6,104	6	83,429	4	384,440
South Korea	8	842	3	222,656	5	235,433
Canada	12	460	17	6,748	6	155,249
Mexico	5	2,789	8	78,326	7	146,194
Taiwan	4	2,835	4	93,265	8	130,717
Hong Kong	1	18,126	5	84,102	9	103,528
Germany	9	729	10	25,937	10	59,719
France	8	904	15	9,851	11	47,092
United Kingdom	11	502	16	8,987	12	40,781
Italy	10	639	18	6,461	13	25,331
Ireland	2	8,025	12	17,563	14	21,824
Brazil	-	0	14	10,819	15	14,048
Netherlands	6	988	20	1,833	16	5,467
El Salvador	-	0	9	38,620	-	-
Indonesia	-	0	13	14,517	-	-
Portugal	14	97	19	2,420	-	-
Other	-	394	-	9,670	-	241,146
TOTALS	-	43,434	-	1,352,317	-	3,533,315

Source: Census Bureau Foreign Trade Data Printouts, 1978. 1987 data from U.S Department of Commerce, Bureau of Industrial Economics Office of Producer Goods, Science and Electronics Division.

TABLE 5.8

U.S. Exports ofMicroelectronic Devices to Principal Country Markets 1967, 1977, and 1987 (in thousands of dollars)

IMPORTED FROM	RANK	1967	RANK	1977	RANK	1987
Malaysia	52	8	1	244,673	1	722,386
Singapore	47	11	2	224,971	2	425,448
Philippines	31	81	9	63,557	3	385,175
South Korea	15	1,682	3	142,635	4	226,597
Canada	6	13,685	12	37,584	5	221,966
Mexico	9	5,688	6	84,587	6	210,608
Germany	8	10,588	4	112,848	7	175,953
Japan	5	15,773	7	75,731	8	162,745
Hong Kong	3	16,303	5	101,229	9	136,023
Taiwan	12	3,365	8	73,933	10	105,413
France	4	16,284	11	52,892	11	103,176
United Kingdom	1	18,768	10	60,771	12	92,530
Italy	7	10,658	15	23,155	17	32,955
Brazil	18	627	18	16,498	14	21,478
Netherlands	11	4,738	17	20,089	15	16,826
Ireland	10	4,796	20	12,675	16	12,864
Belgium + Luxembourg	16	1,289	13	25,752	-	-
El Salvador	43	13	14	24,871	-	-
Switzerland	2	18,189	16	20,922	-	-
Thailand	42	15	19	15,597	-	-
Other		9,455		68,159		420,244
TOTALS		151,981		1,503,129		3,472,372

Source: SIA printouts, 1987 and Census Bureau Foreign Trade Data Printouts, 1988.

assembly operations (Table 5.8). Imports and exports of microelectronic products to and from Japan, Germany, the U.K., the Netherlands, and other European nations consist of finished microelectronic products.

This type of international trade in microelectronic products takes place because of specialization in specific microelectronic manufacturing sectors.

International trade in microelectronics has increased dramatically over the last decade for several other reasons. The first pertains to the fact that the use of microelectronic components in various products has been accelerating in all industrialized countries.

The second is that at any one period of time, a country, even one which has a significant microelectronics industry, may not have sufficient capacity to manufacture all types of microelectronic products required at a specific time. There may exist a temporary under-capacity for the production of certain types of microelectronic devices (Soete, 1985; Cheng, 1984). For example, in the early 1980's the U.S.' capacity to manufacture 64K RAMs was very limited, hence these were imported in large numbers from Japan. Conversely, the Japanese capacity to manufacture microprocessors in the early 1980's was negligible, causing most to be imported from the U.S. (SHC, 1984). This phenomenon is, of course, supportive of and supported by modifications to the classical economic theory advocated by Posner (1961), Mansfield (1981) and Maskus (1983).

The third reason for increased international trade in microelectronics lies in economies of scale. It has been well established that as the volume of production of a microelectronic device increases, the production costs decrease.(1) This in turn allows for decreases in the selling price, which are in fact induced by competitive pressures (SHC, 1984 and 1986). Thus, at any one time the selling price of a microelectronic device produced by one country may be significantly lower, because of the effect of production scale, than the price for the same device in another country which has not been able to expand production facilities to the same extent. Under such conditions the international demand for microelectronic products will be met by the country with the lowest selling price as presented in the theoretical framework by Gruber, Mehta and Vernon (1967). Because transportation costs represent only a very minor element in the total cost of microelectronic products, they are unlikely to offset these price advantages. This factor, therefore, enhances international trade in these products.

Finally, the relative absence of significant tariff and non-tariff barriers by most countries which manufacture and/or consume microelectronic products adds still another reason for flourishing international trade (OECD, 1984).

In summary, the worldwide microelectronic industry in 1988 can be characterized as an extensive sharing of semiconductor technology advances among all countries which manufacture semiconductors. This technology sharing is accomplished using a number of formal devices, such as technology licensing agreements, sale of patents and technology exchange. (Modigliano and Balcet, 1983). Essentially all semiconductor firms have undertaken technology exchange using one or several of these means.

5.3 TECHNOLOGY ADVANCES IN THE MICROELECTRONICS INDUSTRY

Advances in technology in the microelectronics industry have been described as "phenomenal" (Noyce, 1981). Indeed, as shown in Table 5.9, critical technology measures in the microelectronic industry indicate phenomenal advances. An aggregate measure of the microelectronic industry's technological advances show the technology index increasing from 1.0 in 1966 to 198.77 in 1988, Table 5.10 (Gutmanis, 1988). A significant body of technical literature exists on this subject and need not be repeated here (Noyce, 1971; Ozawa, 1974; Johnson, 1982; OECD, 1985). There are, however, certain outcomes from these advances in microelectronics technology which have significant economic impacts, and which in

TABLE 5.9

Selected Technology Change Measures
Microelectronics Industry:
1965 - 1988

AVERAGE[1] YEAR	WAFER DIAMETER CHIP DIMENSION	AREA	NUMBER OF TRANSISTORS PER CHIP
1965	30	6	1,000
1970	50	18	4,000
1975	100	40	16,000
1980	125	74	256,000
1985	175	200	1,000,000
1988	200	240	4,000,000

1. In micromilimeters.

Source: For 1965 to 1979 adopted from R.N. Noyce, "Large-Scale Integration: What is yet to come?", Science, 18, March 1977. For 1980 to 1988 - Sterling Hobe Corporation, 1988.

TABLE 5.10

Overall Index of Technology Change in Semiconductor Industry, 1960 - 1988

YEAR	INDEX
1960	1.00
1965	6.71
1970	14.52
1975	47.41
1980	99.89
1985	139.86
1988	198.77

Source: I. Gutmanis, Technology Measure of Semiconductor Industry, Prepared for the National Science Foundation, SHC, Occasional Paper No. 27 (revised) 1988.

turn have had pronounced policy implications. These economic impacts may be identified as:

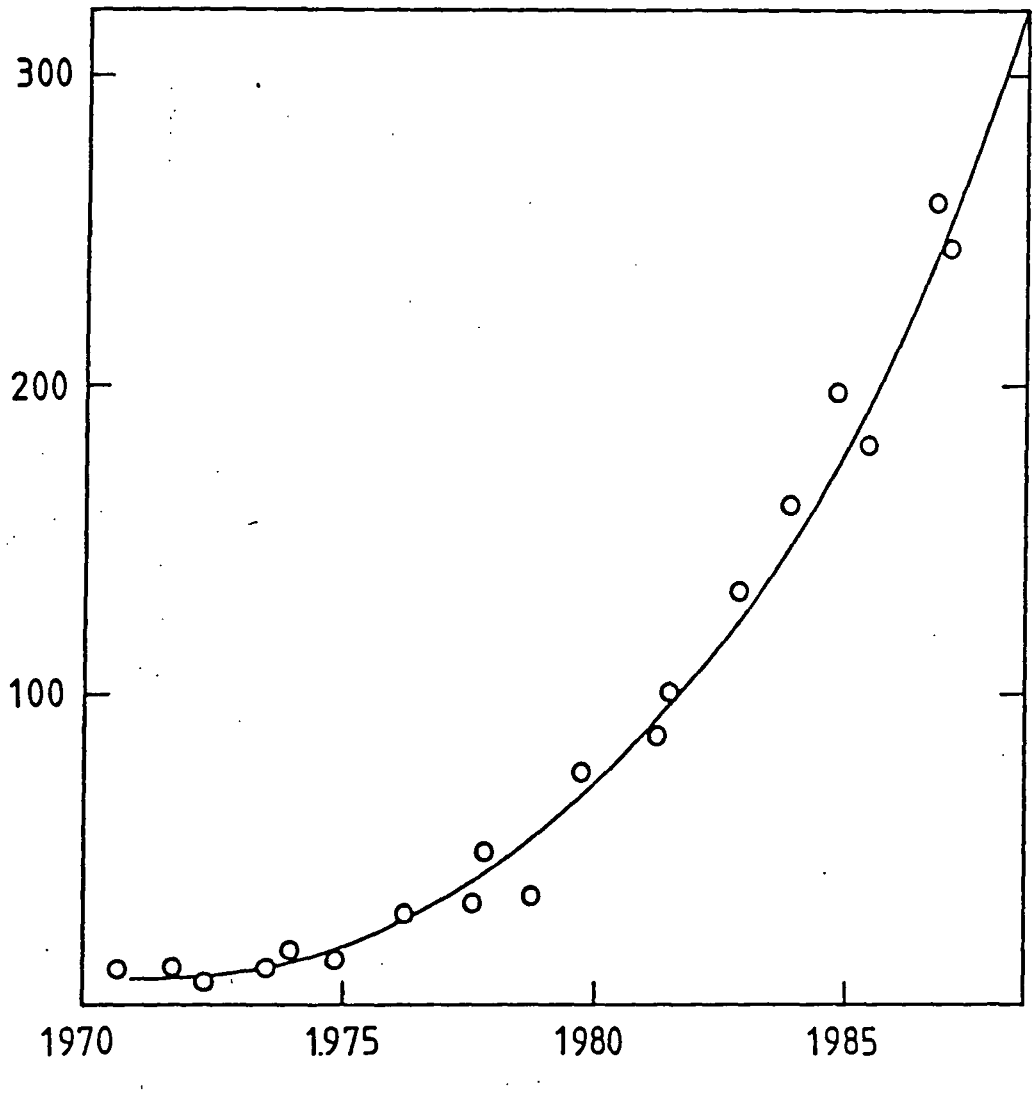
a. The significant increase in the cost of manufacturing microelectronic products, in particular an increase in the cost of manufacturing equipment;
b. The rapid obsolescence of microelectronic product lines;
c. Secular trends in the reduction of the costs of microelectronic products.

5.4 COSTS OF MICROELECTRONIC PRODUCT MANUFACTURE

The rapid advances in the technology of microelectronic products have brought about an equally rapid increase in the costs of equipment used in their production. Of equal importance, the labour costs of microelectronic product manufacture have also rapidly increased. The design and layout of a typical microelectronic product (integrated circuit) required in 1987 was about 300 man-hours per month, as compared to about 30 man-hours in 1970 and about 4 man-hours in 1960 (Figure 5.2). The personnel costs of operations and maintenance in microelectronic industry plants in the U.S. increased by 137 percent between 1969 and 1980, only to increase again by 112 percent between 1980 and 1987 (Gutmanis, 1988). It is, however, in the costs of equipment and machinery used in microelectronic product manufacture where cost increases have been particularly large.

Figure 5.2

Estimated Man-Hours Required
for Integrated Circuit Design,
United States, 1970 - 1988
(in man-hours)



Source: SHC, 1988.

For example, the "floor" price of Perkin-Elmer's Micralgin projection mask aligner, one of the most commonly used items in microelectronic components in 1979, was $210,000 for the most advanced model (Micralgin 300). The cost for Microalgin Model 500, the most advanced available in 1980, was $680,000. The most advanced Perkin-Elmer model in 1988 cost approximately $1.5 million. The most advanced projection mask aligner equipment based on x-ray etching/synchrotron technology (announced in 1988) was estimated to cost $500 million.

Of course, each successive model of projection mask aligner, in addition to the higher cost, brings forth significant improvements in production technologies (Table 5.11). The considerably higher equipment costs, however, may prevent certain firms and countries from entering this industry, and at the same time, encourage other firms and nations to enter and benefit from limited competition.

As a result of the rapid technological developments in microelectronic product manufacture, the total initial investment costs for microelectronic product facilities have increased at a very rapid rate. Whereas in the late 1960's a basic representative facility for microelectronic component manufacture cost about $2 million, the comparable cost of such a facility in the mid-1970's was $50 million; in early 1980 it was $80 - $100 million, and in 1987 it was estimated at $160 million (ICE, 1988). Tables 5.12

TABLE 5.11

Comparison of Semiconductor Printing Methods, 1975 - 1986

	Projection Printing		Direct Step on Wafer	E-Beam Direct Write on Wafer
	Perkin-Elmer 1975	Cobilt 1977	GCA 1983	Etec 1986
Cost per machine	$170,000	$210,000	$400,000	$1,300,000

Source: SHC, 1988.

TABLE 5.12

Selected Typical Microelectronic Facility and Equipment Costs, 1970-1988

FACILITY COMPONENT	YEAR/TYPICAL COST 1970	1975	1980	1985
Wafer Testers	250,000	3,000,000	4,800,000	7,000,000
Printers	120,000	170,000	210,000	1,300,000
Clean Room Environment Equipment	210,000	390,000	1,100,000	2,400,000
Material Quality Laboratory	60,000	240,000	1,200,000	1,200,000
Total Facility Cost	20,000,000	45,000,000	100,000,000	300,000,000

Source: ICE, 1988 and SHC, 1988.

and 5.13 present typical microelectronic equipment and facility operations costs for the 1970 to 1988 period.

As the information presented suggests, the capital costs of equipment and facilities to manufacture microelectronic products have increased at a very rapid rate. The requirements for very large capital outlays to establish a microelectronic products facility have created considerable difficulties for new entrants in this industry sector, unless financial assistance is provided by appropriate governmental programmes.

These cost increases in equipment have resulted in very rapid increases in total capital expenditures in the micro-electronic industry. In the U.S., the annual capital expenditure in the microelectronic sector increased from $1.2 billion in 1980, to $2.8 billion in 1985, to $3.4 billion in 1988. In Japan, the corresponding figures are $0.4 billion in 1980, $2.7 billion in 1985, and $3.0 billion in 1988 (Figure 5.3).(2) A good measure of the intensity of capital expenditures in the microelectronic sector can be seen from the proportion of total sales expanded for new capital, as shown for microelectronic firms in Japan and the U.S. for the 1981 to 1987 period:

	1981	1982	1983	1984	1985	1986	1987
Japan	17%	19%	21%	38%	32%	36%	34%
U.S.A.	18%	16%	14%	19%	14%	16%	15%

TABLE 5.13

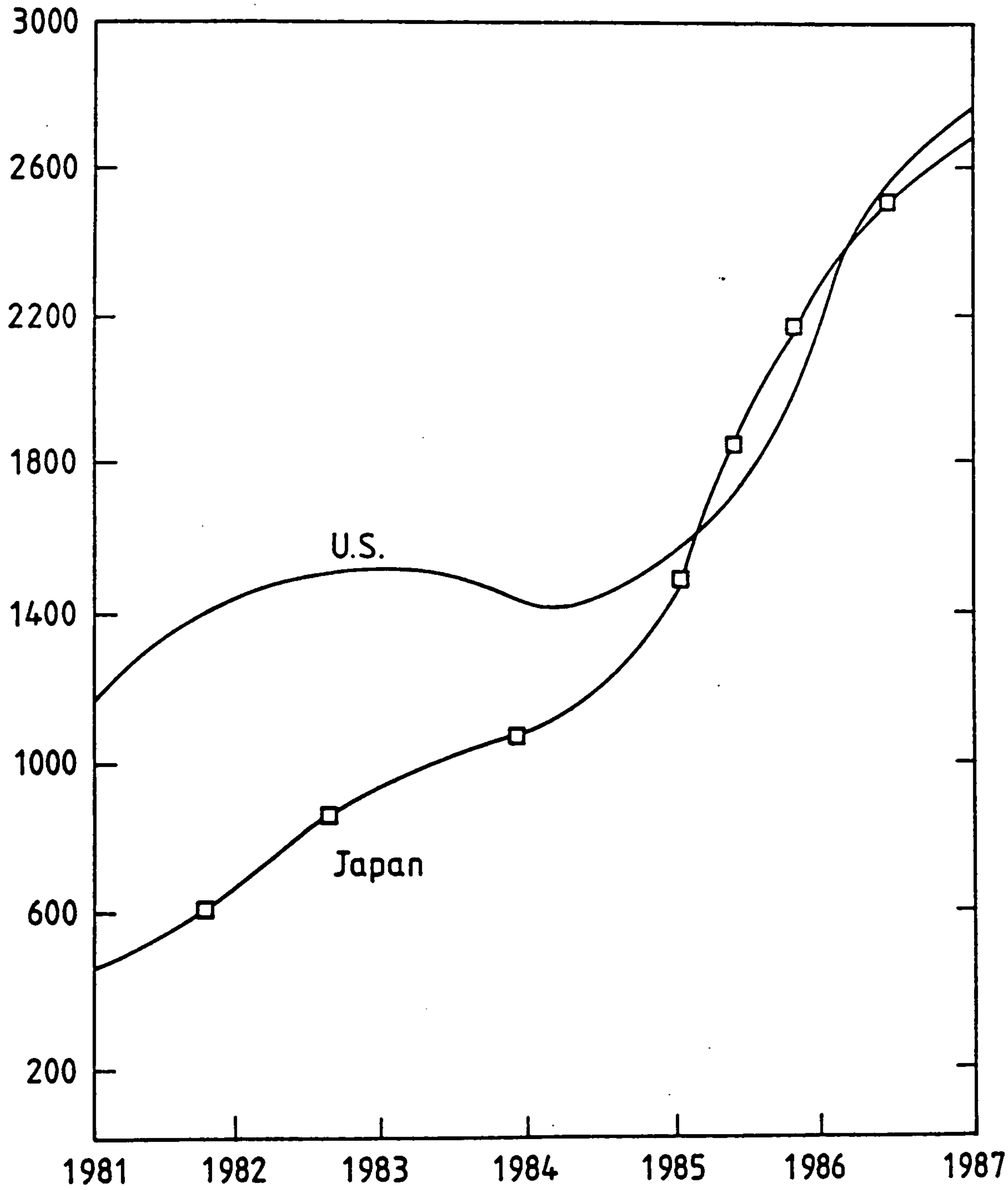
Typical Microelectronic Facility
Operations Costs, 1970-1988

OPERATION/ COST ITEM	YEAR/TYPICAL COST 1970	1975	1980	1988
Wafer Processing Cost	$72.90	$85.00	$170.00	$400.00
Depreciation Costs per Wafer	22.00	27.00	58.00	150.00
Wafer Test Costs per Wafer	0.07	0.12	0.20	0.55
Total Probe Costs	3.10	5.16	9.40	29.66

Source: ICE, 1988 and SHC, 1988.

Figure 5.3

United States and Japan Micro-
electronic Industry Capital Expenditures,
1981 - 1987
(in millions of current dollars)



Source: SIA Printouts (1988).

These increasing requirements for capital expenditures have placed considerable pressure on the management of microelectronic firms to generate the required funding by increasing sales volumes and profits. When and where the required increase in sales and profits did not materialize, a microelectronic firm was either forced to go out of business or seek the monies required for capital expenditures from other sources, such as government funding.

5.5 OBSOLESCENCE OF MICROELECTRONIC PRODUCT LINES

One result of the rapid technological advance in the microelectronic industry has been the introduction of advanced microelectronic product lines and the obsolescence of older product models. An excellent example of this can be seen in the changes over time of the most commonly used memory devices in microelectronic products, the so-called Dynamic Random Access Memories (DRAMs). As the technology of the microelectronic memory devices advanced, the capability to hold within one device (approximately 1/2-inch square in size) the components (or bits) of information increased from 16,000 in 1970, to 64,000 in 1979, to 256,000 in 1983, to more than one million in late 1986.

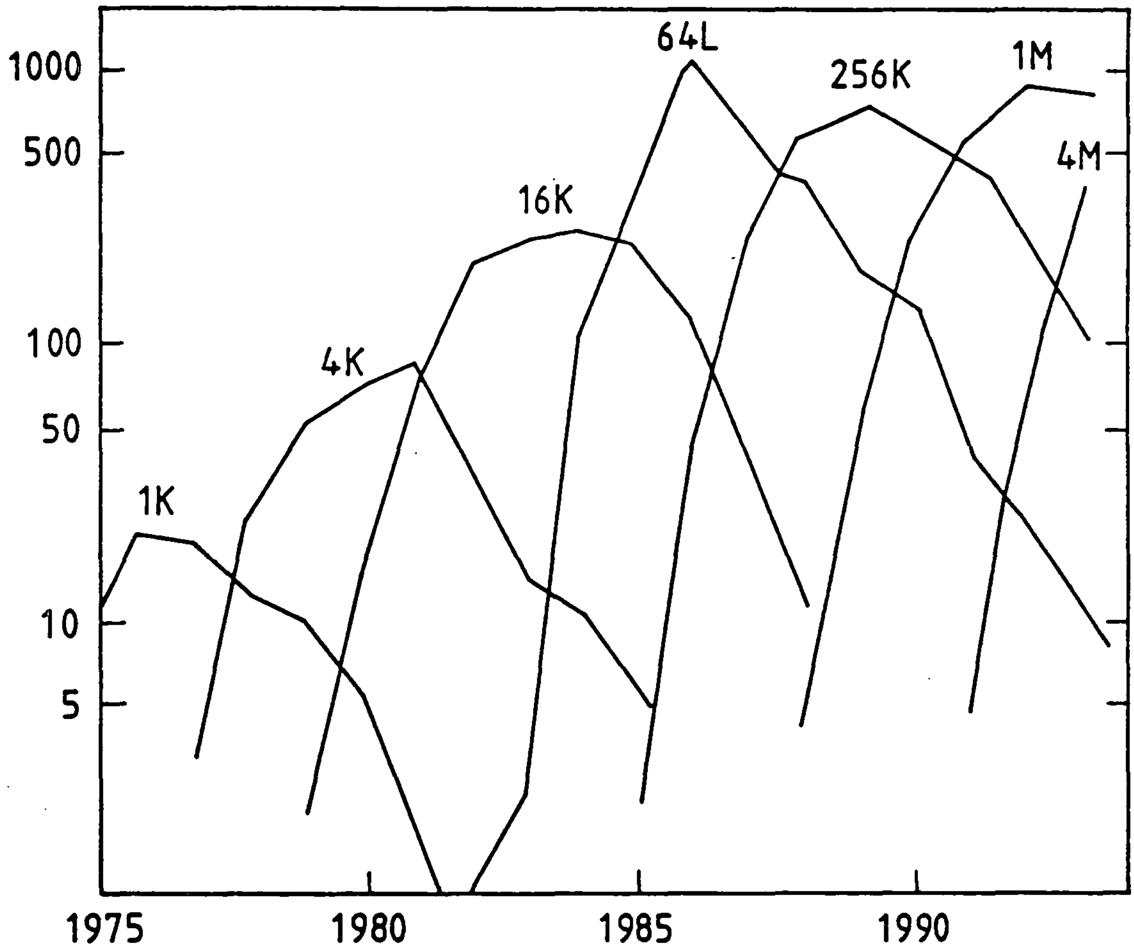
These advances in technologies or product performance were not accompanied by increases in costs, as discussed in the following section. The overall result of this has been relatively short model life cycles, as shown in Figure 5.4.

This obsolescence of microelectronic product lines has several important cascading implications, which culminate either in government policies to dampen the impact of these obsolescence trends on their microelectronics industry, or withdrawal from the industry if such policies are not enacted. The chain of cascading implications starts with the need for additional capital and related expenditures for the advanced microelectronic product lines.

For example, while the machinery and equipment required for 1K and 4K memories were essentially the same, and relatively modest additional expenditures were required to convert 1K memory manufacturing facility to 4K memory production, conversion from 4K production to 16K production was relatively costly. Further, 16K memory manufacturing facilities then became essentially obsolete with the manufacture of 256K memories, and new production facilities were required (SHC, 1986). It has been reported that for a comparative facility (in terms of output per unit of time) the costs of a 256K facility was five to six times as much as for a 16K facility (SHC, 1988). In Japan and in some of the NICs, the government often provided direct or indirect funding for such new facilities. In the U.S., the funding for these capital expenditures was left to the private sector. U.S. private capital

Figure 5.4

Worldwide Shipments of
Dynamic RAMS by Types of Model,
1973-1993



Source: ICE, 1988.

sources could not finance the required expenditures and the memory market segment of the microelectronics industry was essentially monopolized by the Japanese.

In 1977 the Japanese held approximately 47 percent of the world's memory market, by 1987 the Japanese were producing almost 86 percent of all memories. Government policies have other, but related, impacts on microelectronics industries in each country.

The consistently increasing cost of manufacturing advanced lines of microelectronic products and the relatively short time span for each line of microelectronic products, required that the production or output from these manufacturing facilities be as large as possible over a period of time in order to generate sales volume and income. This would then allow the existing manufacturing facilities to depreciate in real terms before new and advanced facilities needed to be constructed. Many capital formation issues, including depreciation schedules, are subject to governmental regulation. Here again, the Japanese regulations favour the microelectronics industry, whereas U.S. capital depreciation rules do not.

The need for capital expenditures by the microelectronic sector, a need which is continuous and does not conform to the capital requirements of most other sectors of industry, provides governments with the opportunity and/or the need to enter into the microelectronic sector with certain policies and/or regulations regarding various capital formation issues (OTA, 1984). As presented in Chapters 8 to 12, there are significant differences between contries with such regulations.

The very same considerations also encourage some governments to undertake policies which increase the production of micro-electronic products over a specified time period. Increased production of microelectronic products over time may be achieved _via_ two alternate approaches:

a) fuller utilization of the existing facilities; or

b) construction of larger facilities in order to reap the benefits of economies of scale.

These two approaches are not always substitutable but there do exist opportunities or some degree of freedom to alternate between these two approaches. Most important, such alternate approaches provide governments with an opportunity to direct the production schedules of microelectronic goods via certain policies (OECD, 1985). Here again, as discussed in Chapters 8 to 12, while the Japanese government (and to a certain extent the South Korean and Singapore authorities) have taken advantage of this, the U.S. government and the governments of the EC have not.

5.6 SECULAR COST TRENDS OF MICROELECTRONIC PRODUCTS

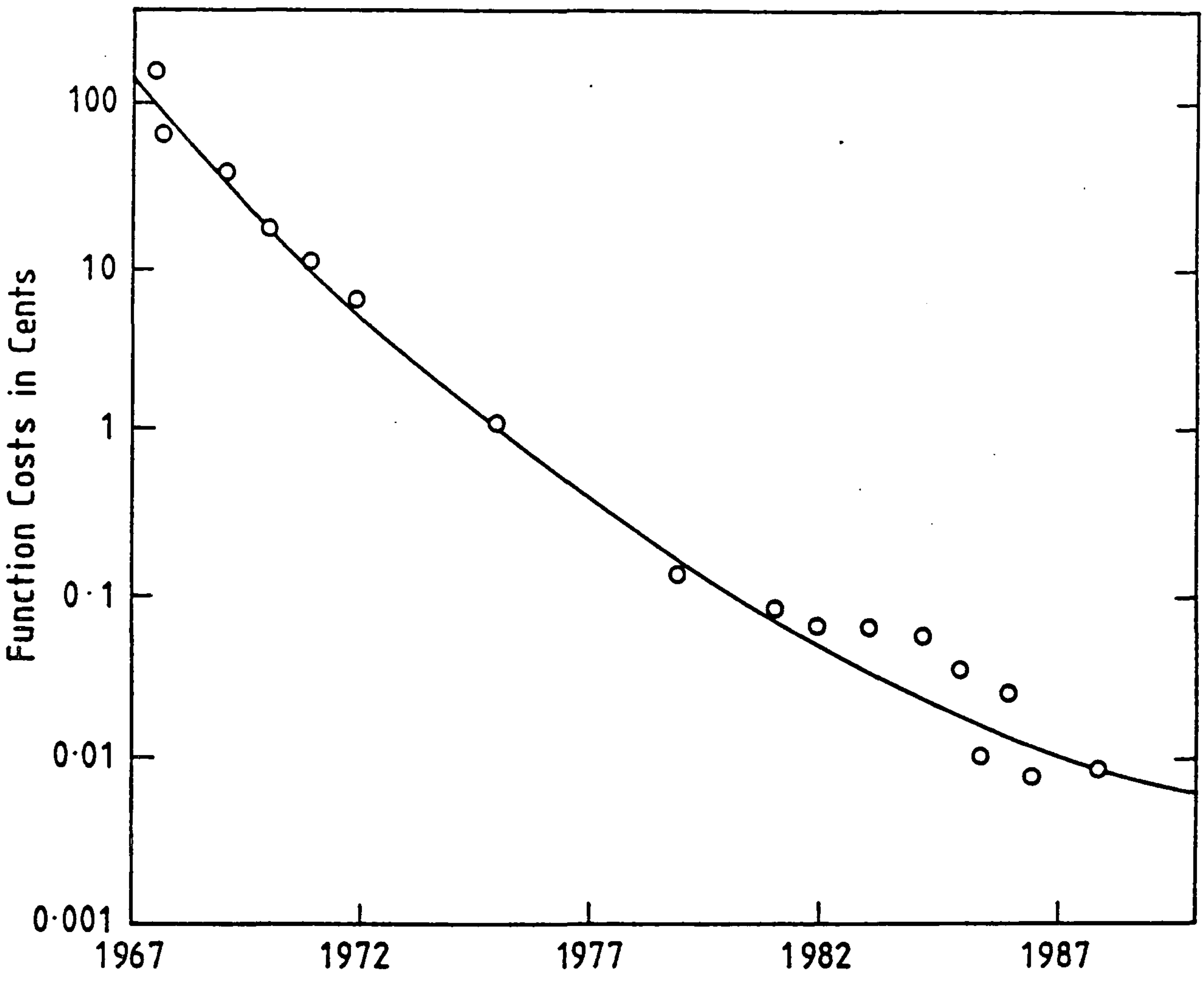
There is considerable empirical evidence, collected over the last twenty years, that production costs for most microelectronic products decline signficantly over time. The manufacturers of microelectronic products have responded to this by lowering the selling prices over time (U.S. ITC, 1984; SHC, 1986). This decline results from the effects of the "learning curve" impact and has been subject to numerous studies and reports (Bowen, 1980; Dosi, 1988; SHC, 1986). The empirical evidence substantiates such assertions. For example, Figure 5.5 presents the selling prices of dynamic RAMs for the 1975 to 1988 period as a function of the cumulative values of products. The SIA states the following regarding this decline in selling price:

> It is noteworthy that between 1975 and 1980, world dynamic RAM prices declined in a highly consistent pattern. With only minor deviations, the RAM price per bit declined along a "70 percent slope"--that is, the price per bit consistently fell at a rate of 30 percent for each doubling of cumulative industry output. The 70 percent slope in effect reflects the experience of the entire industry and all generations of RAMs over an extended period. Through 1980 this slope remained constant despite recession, entry and exit of competitors, intense competition, and the introduction of new generations of RAMs. The 1975 recession caused only a very slight deviation from the 70 percent slope. The introduction of a new RAM generation (16K), quadrupling the number of bits on a chip, did not cause a noticeable break in the 70 percent slope (SIA, 1983).

The decline in selling costs for microelectronic products is a standard phenomenon. For example, in the case of microprocessors,

Figure 5.5

Average Price per I-C Function,
United States, 1967 – 1988



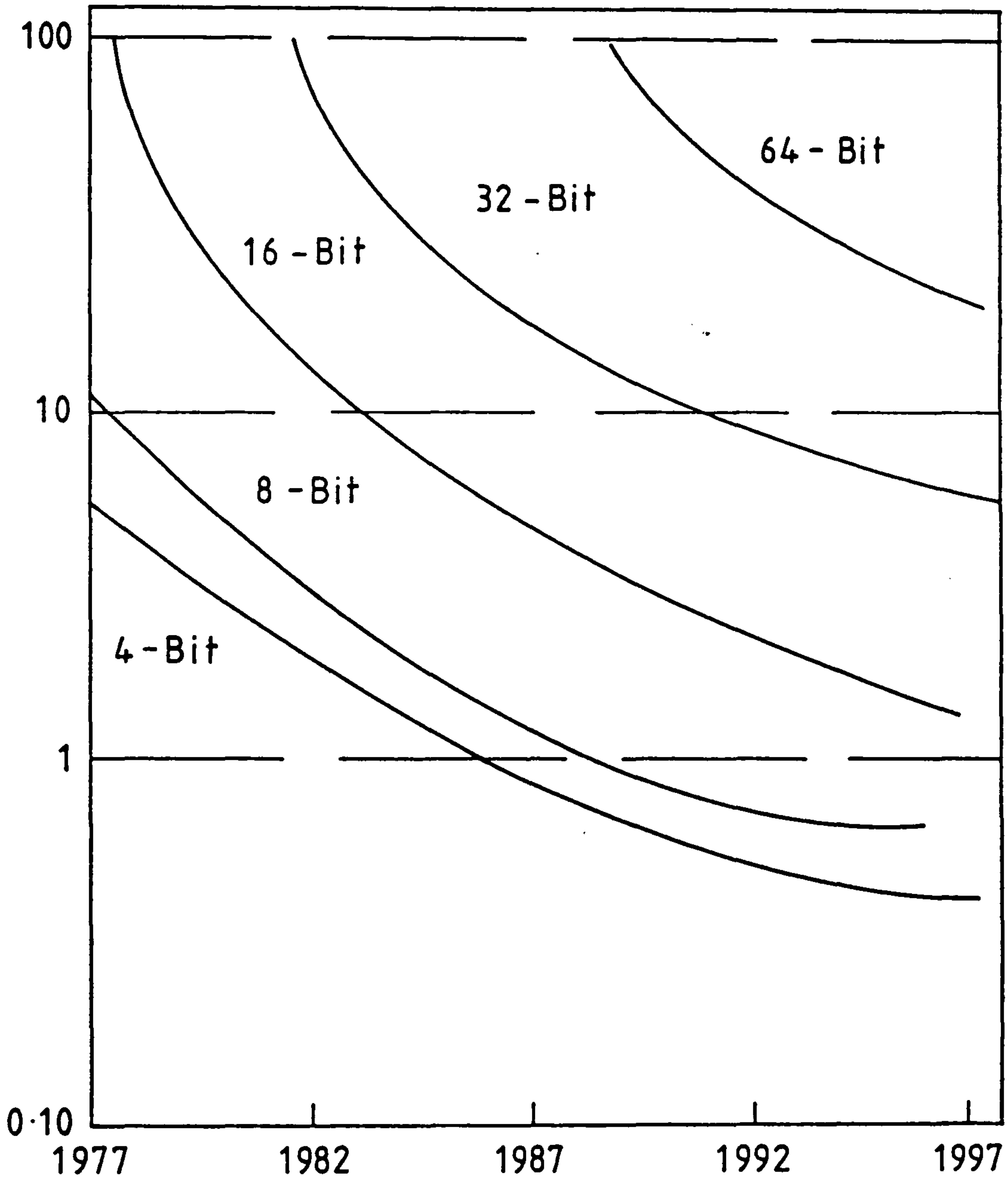
Source: Derived from Dataquest information releases 1973, 1981 and 1987.

shown in Figure 5.6, the decline in cost over a twenty year period has been exceptionally significant, and has been governed by the manufacturers' learning curves. The 4 byte microprocessor, the most frequently used at the present time (1988) sells for approximately $0.60. In 1977 the cost of this component was $15.00. The 16 byte microprocessor, used most frequently in the manufacture of personal computers, has decreased in price to less than $6.00 as of March 1988, compared to over $100 for the same product sold in 1977 (SHC, 1988). Similar decreases in costs can be seen for the 32 byte microprocessor, which has declined from $100 in 1982 to approximately $55 in 1988.

In all cases, however, these declines in selling prices will eventually be arrested because of the requirements for large capital expenditures. These trends, in turn, create an environment in which the need for timely capital outlays, generation of sales volume, conversion and/or start-up of advanced product lines are extremely important. Appropriate goverment policies are well suited to foster such actions. It is important to note, however, that the "appropriate" government actions may not be those typically regarded as proper for governments to undertake, such as fostering basic research education or even research and development. Rather, appropriate government policies in this context are taken to mean intervention in the market economy. Such intervention would represent a radical departure from the principles of

Figure 5.6

Median Microprocessor Price vs.
Time, United States, 1977 - 1997
(in cents per unit)



Source: ICE, 1988.

classical economic theory to which, at least in the U.S., government officials have paid certain attention. The governments of the U.S. and some of the EC nations have been reluctant to undertake such intervention. The Japanese government, partly because of the post-World War II practices (and established traditions stretching backing to the beginning of the Meiji era) have undertaken such intervention with vigour.

5.7 TECHNOLOGICAL DISPERSION IN THE WORLD MICROELECTRONIC INDUSTRY

The international dispersion of the microelectronics industry since the mid-1970's has been unequalled in the history of industry. The growth of semiconductor manufacturing in countries like Japan, France, Germany, the U.K., South Korea and Taiwan has been for the most part facilitated by the transfer of technologies from the U.S. The single most important characteristic of the international spread of microelectronic product manufacture in Japan and NICs is government policies directed towards commercialization, i.e. the manufacture of microelectronic products immediately after such products are designed and engineered, either at native R&D establishments or obtained from other nations, principally the U.S.

Another feature of the international diffusion of microelectronics technology is the rapid increase in cooperative R&D

and engineering efforts among countries. Most of these cooperative projects include private sector and academic alliances and many involve government support and coordination.

There have also been an increasing number of technical partnerships across national boundaries formed between two or more manufacturers of microelectronic products. These activities have transformed the microelectronics industry into an international enterprise, members of which are individual countries trading with other nations in microelectronic products (Dosi, 1988).

Siemens of Germany is an outstanding example of this. Siemens represented one of the 12 original companies that stimulated the establishment of the European Strategic Programme for R&D in Information Technology (ESPRIT). Siemens has also established the Mega Project, a partnership with N.V. Philips in the Netherlands to develop certain semiconductor memory products, and the European Computer Research Center (ECRC) with two British firms, Bull and ICL. In addition, Siemens has a 25 percent equity interest in the U.S. semiconductor firm Advanced Micro Devices (AMD) and has technical agreements with Analog Devices, American Microsystems, Intel and Zilog (Gutmanis, 1986).

Skolnikoff (1983) has summarized the emergence of the international microelectronics industry as follows:

a) International affairs have been heavily influenced by the differential ability of nations to carry out and capitalize on the results of R&D.

b) Traditional geopolitical factors that have been the guts of international relationships have been substantially altered or expanded by advances in science and technology.

c) The results of R&D have also given rise to new technologies of global scale, creating wholly new issues in international affairs, notably atomic energy and space exploration, or have greatly altered traditional issues such as trade, transportation, and economic competition.

During the last several decades, coöperative international agreements have been established resulting from scale requirements for production, technical competence, facilities, capital, and market access. The major role in these international cooperative agreements is played by the private sector, with multinational enterprises as the principal players. The dominant role of multinational enterprises in these cooperative activities is obvious since multinationals account for approximately 75 percent of all industrial R&D spending in the OECD countries (OECD, 1985).

These international agreements are dominated by joint ventures, patent agreements, second sourcing, joint R&D efforts, and country market representation. Contractor (1980) addresses the notion of "transcontinental cooperation" as follows:

> All these arrangements exemplify a concept of international competition very different from the usual view of Europe, the United States, and Japan as committed rivals. Rather than closing ranks on a European, or

> American, or Japanese level, with each side attempting to rely only on itself, all three sides of the triangle which today guides world technological and economic development have an interest in reinforcing the system as a whole. To this end, each partner must be in a position to contribute as best it can in the light of its preparation, its technical, organizational and managerial capabilities, and even its culture -- its distinctive way of looking at the world and its vision of the future.
>
> This does not mean reduced competition. On the contrary, competition must become even more lively and constructive in an imaginative partnership, where each partner is aware of his role in a complex system of industrial democracies.

Clearly these trends towards international cooperation in the microelectronics sector have some impact in levelling national comparative advantages. However, this levelling effect may be limited because of the very large number of different technologies used in microelectronic product manufacture. The OECD (1985) report addresses the issue of comparative advantage as follows:

> The priorities of Member (OECD) countries are concentrated to a remarkable extent, on the same technologies. This commonality of priorities has raised concern that it could lead to an over capacity of the kind that now exists in industries such as steel and textiles. This concern may be premature. The new technologies are numerous and diverse ... In fact, the technologies offer an unusual opportunity for diversifying the economies of OECD countries ... Such diversification, however, requires that countries realistically appraise their prospects relative to others, for exploring specific technologies...

It must be recognized, however, that there exists a secular trend towards "international technological convergence" resulting from a worldwide technological diffusion in microelectronics technology (Mowery, 1983). The trend toward international cooperation in the microelectronics industry and the resulting diffusion of technology which, in turn, has produced both inter-dependence and competition, has been addressed in a number of recent studies (Charles River Associates, 1981; U.S. ITC, 1979; and OECD, 1985).

5.7.1 International Investments and Cooperation

One of the cardinal reasons for the internationalization of the microelectronics industry is the need to sell microelectronic components in the world market. In a number of nations, micro-electronic markets could only be opened and sales realized via some form of cooperation/participation because of government policies. Four types of such cooperation need to be examined.

a) International acquisitions and/or equitiy investments of companies;

b) International investment in microelectronic R&D, production, testing and assembly facilities;

c) International interfirm agreements:

   i - Joint ventures
   ii - Technology exchanges
   iii - Licensing/cross licensing
   iv - Second sourcing; and

d) International private sector research corporations.

5.7.2 International Acquisitions and Equity Investments

International acquisitions and equity investments dominate the international diffusion of the microelectronic industry. The data in Table 5.14 identifies 21 examples of acquisitions and equity investments in microelectronic firms over the last decade.

The bulk of activity shown in Table 5.14 involved the purchase of U.S. firms, in whole or in part, by Japanese and European firms in the 1970's. NEC's 100 percent purchase of Electronic Arrays in 1978 is an example of this. Examples of European activity are the 100 percent purchase of Signetics by Philips in 1979, Siemens purchase of a 20 percent equity stake in AMD, along with a 100 percent purchase of five other companies in the same period, and the 100 percent purchase of Fairchild by Schlumberger.

The U.S. and Japan have made most of the overseas investment in the microelectronic industries, and most of these investments have occurred since the mid-1970's. During the 1960's, only a few major U.S. microelectronic firms made direct investment in microelectronic facilities in Europe. Texas Instruments invested in the U.K. (1957), France (1964), Germany (1965) and Italy (1968). Motorola invested in France (1967) and then in the U.K. and

TABLE 5.14

Reported Acquisitions and Equity Investments (1974 - 1987)

Acquiring Firm	Acquisition/Equity Investment	Year
UNITED STATES		
AT&T	Goldstar (Korea) AT&T acquires 44% of Goldstar	1979-80
Gould	INTERSIL (U.S.) Gould acquires 100%	1981
JAPAN		
Fujitsu	Amdahl (U.S.) Fujitsu acquires 47% of Amdahl	1984
Mitsubishi	Exxon Division (U.S.) Mitsubishi acquires 100% of this semiconductor-related division	1981
NEC	Electronic Arrays (U.S.) NEC purchased 100%	1978
Toshiba	Korea Electronics (Korea) Toshiba purchased 6.25% as part of a comprehensive pact	1983
	Maruman IC (U.S.) Toshiba purchased 100%	1980
EUROPE		
CIT-Alcatel	Semiprocess (U.S.) CIT-Alcatel purchased a 25% equity share	1980
Ferranti	Interdesign (U.S.) Ferranti purchased 100%	1977
GEC	Circuit Technology (U.S.)	1982
Philips	Amperex (U.S.) Philips purchased 100%	1982
	Signetics (U.S.) Philips purchased 100%	1979

TABLE 5.14 (cont.)

Reported Acquisitions and Equity Investments (1974 - 1987)

Acquiring Firm	Acquisition/Equity Investment	
EUROPE (continued)		
Schlumberger	Acutest (U.S.) Schlumberger purchased 100%	1982
	Fairchild (U.S.) Schlumberger purchased 100%	1979
	Membrain (U.S.) Schlumberger purchased 100%	1978
Siemens	AMD (U.S.) Siemens purchased 20%	1977
	Databit (U.S.) Siemens purchased 100%	1979
	Dickson (U.S.) Siemens purchased 100%	1974
	Litronix (U.S.) Siemens purchased 100%	1977
	Microwave Semiconductor (U.S.) Siemens purchased 100%	1979
	Threshold Technology (U.S.) Siemens purchased 100%	1980
Thomson-CSF	Solid State Scientific (U.S.) Thomson purchased 100% of the transistor division	1979
	Mostek (U.S.) Thomson purchased 100% of Mostek from United Technologies	1985

Source: SHC, 1988.

Germany (1969). Government restrictions in Japan precluded investment there, and Japanese semiconductor firms made very modest international investments during the 1960's.

During the period from the mid 1970's to 1988 a large number of transnational investments were made. Japanese firms played a principal role in these activities. (Table 5.15). There were a total of nine U.S. international investments in foreign operations, European firms reported seven such investments; Korean firms reported four and Japanese firms made a total of twenty-one foreign investments in microelectronics firms. These activities were concentrated in the U.S., with twenty-one of the total forty-one investments occurring there. In the case of European firms, three of the seven investments were in the U.S.; all of the South Korean investments were in the U.S., and fourteen of the twenty-one Japanese investments overseas were made in the U.S. Japan and the U.K. (particularly Scotland's "Silicon Glen") were the other major locations chosen for international investment. Investments in Japan were made mostly by U.S. firms. Investments in the U.K. were divided equally between U.S. and Japanese firms. The reason why the U.S. is a prime choice for international investments is the advanced microelectronic technology developed in the U.S. However, the need to establish manufacturing, or at least a service base in proximity to the market, is another reason for this trend; and the U.S. is indeed a large market for microelectronic products.

TABLE 5.15

Recently Reported International Investments: Establishment and/or Expansion in Microelectronic Product Design Production, Assembly, and Testing Facilities, 1974-1988

FIRM	FOREIGN FACILITY LOCATION	INVESTMENT TYPE AND COMMENTS	Year
EUROPE			
Ferranti	U.S.	IC Production	ND
Inmos	U.S.	Development centre and factory	1980
Philips	Japan	Matsushita Electronics	1984
Schlumberger	Japan	Plant for bipolar IC's	1983
SGS-Ates	U.S.	Plant for memory products	1981
Siemens	Austria	Production and assembly of 16 and 64K memory devices	1980
Thomson	Japan	Design centre in Tokyo	1984
KOREA			
Daewoo	U.S.	Has a 64K DRAM capability	ND
Goldstar	U.S.	IC and component design facility	1983
Hyundai	U.S.	Circuit and component design facility	1983
Samsung	U.S.	Producing 64K DRAMs using 5-inch wafer	1983
UNITED STATES			
Intel	Japan	Design centre	
Mostek	Mexico Japan	Assembly facility	1981 1983-1984
Motorola	United Kingdom	Expansion (1981) of memory and microprocessor	1981 and 1984
	Japan	Fabrication, testing and assembly	1984

TABLE 5.15 (cont.)

Recently Reported International Investments: Establishment and/or Expansion in Microelectronic Product Design Production, Assembly, and Testing Facilities

FIRM	FOREIGN FACILITY LOCATION	INVESTMENT TYPE AND COMMENTS	Year
UNITED STATES (cont.)			
National Semiconductor	Israel	Wafer fab plant	1984
	Japan		
	United Kingdom		1979 and 1984
Texas Instruments	Japan	Production and assembly	NL
JAPAN			
Fujitsu	Ireland	Plant for 16K DRAM's	1981
	Man-chester	Fujitsu buys ICL's West Gorton semiconductor facilities	1981
	U.S. (San Diego)	Test and assembly	1980
	(Oregon)		1987
	(California)		1980
	(Massachusetts)		1982
	(Texas)	Gate array design centres	1982
	(Illinois)		1983
	(Minnesota)		1983
	(Georgia)		1983
Hitachi	Germany	Plant for 16K DRAM's and SRAM's	1982
	U.S. (Irving, Texas)	Expansion	1978 1983 1984
Mitsubishi	U.S. (North Carolina)	Facility to assemble DRAM's	1985

TABLE 5.15 (cont.)

Recently Reported International Investments: Establishment and/or Expansion in Microelectronic Product Design Production, Assembly, and Testing Facilities

FIRM	FOREIGN FACILITY LOCATION	INVESTMENT TYPE AND COMMENTS	Year
JAPAN (cont.)			
NEC	Ireland	Assembly and production	1974
	Scotland	Assembly and production	1983
	U.S. (Roseville, CA)	Automated fabrication	1983
	(Sunny-vale, CA)	Design centre	1983
	(Boston, MA)	Design centre	1983
	Germany	Design centre	ND
	Hong Kong	Design centre	ND

ND = No date.

Source: SEC, 1988.

Of particular interest therefore is the substantial investments by Japanese firms in the U.S. that have been made in pursuit of the Japanese aim of becoming the principal microelectronic product producer in the world.

The expansion of Japanese facilities in the United States is part of a well defined international strategy of Japanese microelectronic firms (SHC, 1984). The advantages for U.S.-based locations include access to U.S. software engineers, access to advanced production equipment, and, equally important, access to U.S. markets (Weinstein, Uenohara and Linvll, 1984). The U.S. microelectronic firms and to a lesser extent the French, in turn established their own facilities in Japan.

The location of design centres in Japan by Intel, National Semiconductor, and Thomson (CSF), all established in the 1980's, presumably serves the same purpose as Japanese entries into the U.S. Weinstein, Uenohara and Linvill (1984) point to the effect of this cross investment on the competitive position of the countries' industries:

> By producing 64K RAMs in Japan, the U.S. companies hoped to gain access to the Japanese market, take advantage of Japanese manufacturing efficiency to produce devices for exports to other markets, and gain access to Japanese capital. By establishing factories in the United States, Japanese companies hoped to gain better access to the U.S. market, including the custom and semi-custom markets, and at the same time gain access to U.S. software-engineering talent. One industry expert predicted that by the mid-1980's as much as 50 percent of each country's VLSI products might be produced in the other, and each industry would be

able to draw on the other country's strengths to overcome its own weaknesses.

The rate of foreign investment in the U.S. has increased very rapidly. Pugel (1985) noted that in 1975, foreign firms had less than 2 percent of the U.S. capacity, but by 1984, foreign firms controlled about 35 percent of the U.S. capacity in microelectronics. The EC firms followed the Japanese example and have also made significant investments in microelectronic facilities in the U.S.

There exists a marked contrast between European and Japanese investment in the U.S. European firms have selected acquisitions and equity investments in existing microelectronic firms as the principal avenue of entry in the U.S. markets (Pugel, 1984). On the other hand, Japanese firms have chosen "greenfield" or de novo entry as their principal approach to the U.S. markets. The main reason for this difference is that European microelectronic firms depend much more on U.S. technology and are reluctant to begin their business ventures in the U.S. alone, whereas the Japanese, by the early 1980's, were much more confident about challenging the U.S. on its own ground.

5.7.3 International Interfirm Agreements

International interfirm agreements have also increased rapidly and present still another channel of microelectronic technology transfer across national boundaries.[3] A total of 121 international technical agreements between microelectronics firms have been reported since 1978. A number of different agreements are made including technical exchanges, joint ventures, cross-licensing, second sourcing and others -- often in combination.

An analysis of the geographical distribution of these agreements shows that alliances between U.S. and Japanese companies dominate interfirm agreement actions with 63 agreements signed. There have been 35 agreements made between U.S. and European firms, while only four intra-European agreements are recorded (SHC, 1988).

South Korea probably has the strongest technological potential in the microelectronic industry among the developing nations. This fact is manifested by the high number of agreements with South Korean firms throughout the 1980s; 19 were reported in 1984; 11 in 1985; 7 in 1986; 11 in 1987; and 17 in 1988. The principal reason for these U.S.-South Korean agreements was the need for U.S. firms to take advantage of low cost manufacturing in South Korea in order to compete with Japanese firms and to gain a foothold in the expanding South Korean market (Richardson, 1983).

5.7.4 Other International Ventures

There are several other types of international ventures that have played a role in the international diffusion of microelectronics products.

In Europe, the ECREC and ESPRIT have participated in the diffusion of microelectronics industry technologies among EC member nations, and to a much lesser extent among other countries as well.

The ECREC was established in 1983 by ICL of the U.K., Bull of France, and Siemens of Germany. It's objectives are research in computer-aided design, voice and network software, and the more advanced areas of the microelectronic industry.

Because the most advanced research efforts in these technology areas are conducted in the U.S. and Japan, the ECREC has established close technical liaisons with U.S. and Japanese firms. The 8-year, $4 billion Joint European Submicron Silicon Initiative (JESSI), approved in June 1989 by the 12 member states of the EEC is another example of international ventures in the microelectronics industry.(4)

ESPRIT, also established in 1983, focuses on long lead time R&D in basic underlying technologies, or "precompetitive" technical areas related to advanced microelectronics. Their stated objective is "to provide the European IT industry with the technology base it needs to become and stay competitive worldwide in the next ten years" (E.C. Bulletin, 1980). Assumed as a ten-year effort, the programme's first five-year phase is being funded at approximately 1.5 billion ECU's, or about $1.25 billion, of which half is coming from the EC and half from industrial, academic, and/or institute research performers.

Two key issues which the ESPRIT programme will address impact on the competitiveness of the European electronics industry: (1) generating sufficient R&D funds for long-term projects in the face of declining sales; and (2) overcoming traditional political and economic rivalries to achieve colaboration (Dickson, 1987).

A total of 12 companies, which represent 70-80 percent of European industrial research facilities in this field, are members of ESPRIT. They are listed in Table 5.16.

At the time of ESPRIT's establishment, its specific objectives were the following:

a) Ensuring that research teams achieve the critical size to obtain results.

b) Enabling optimization of resources that will result in reducing duplication and widening the spectrum of research tackled.

TABLE 5.16

ESPRIT Steering Committee Grouped by Home Country

United Kingdom

GEC
ICL
Plessey

Federal Republic of Germany

Nixdorf
Siemens
AEG

France

CII-Honeywell Bull
Thomson-CSF
Compagnie Generale de l'Ectricitie

Italy

Olivetti
STET

Netherlands

Philips

Source: SHC, 1988.

c) Reducing the timelag effect caused by reliance on imported technology.

d) Paving the way to the definition and adoption of standards of European origin. (E.C. Bulletin 5, 1980).

Table 5.17 presents the technical areas in which research is undertaken by ESPRIT.

A major criterion for participation in ESPRIT is a cross-frontier partnership between at least two research performers, one of which may be "commercially oriented" and "preferably an EC industrial company" (E.C. Bulletin 3, 1984).

Several characteristics of ESPRIT must be noted. It is an international programme with the basic objective of establishing critical linkages among the research resources of member countries. By operating through the European Community, ESPRIT is developed with, by, and for European industry.

By January 1988, a total of 178 projects had been approved by ESPRIT representing an EC financial commitment of about $211 million.

TABLE 5.17

ESPRIT Technical Areas and Applications

TECHICAL AREAS	FOCUS
ENABLING TECHNOLOGIES	
Advanced Microelectronics	Development of submicron MOS and bipolar integrated circuit technology and the related computer-aided design tools
Software Technology	Development of a new generation of modular and reusable software production tools which can also be used in other sectors of the programme
Advanced Information Processing (AIP)	Development of a new man-machine communication linkages, knowledge processing techniques, and novel computer structures
APPLICATIONS	
Office Automation	Research into work stations and related communication and data links for office systems
Computer Integrated Flexible Manufacturing	Development of systems for factory automation which relate to architecture of integrated systems, robotics, sensors, and transducers

Source: OECD, 1985.

The design of ESPRIT is clearly intended to benefit European industry. Participation by non-European companies is not prohibited, but it is limited to those non-European firms with large R&D activities in Europe.

For the U.K. companies, particularly GEC, ICL and Plessey, there was and remains a question of participating in a national programme, Alvey, versus an international programme, ESPRIT. (See Chapter 10).

In summary, the following are the salient characteristics of the international agreements in microelectronics:

a) U.S. firms were the most active in establishing such agreements followed by Japanese firms, European firms, and South Korean firms;

b) Agreements between foreign and U.S. companies are clearly the most pronounced, with U.S.-Japanese agreements most numerous;

c) Five companies dominate: Intel, Motorola, NEC, Hitacchi and N.V. Philips;

d) The technical subjects of agreements cover a broad spectrum; and

e) Most agreements reflect a bilaterial blending of technical strengths.

The dominant pattern in these agreements is the exchange of technology for technology. These agreements include:

a) technology sharing agreements

b) joint and/or complementary development accords

c) customer-supplier partnerships

d) joint research pacts.

5.8 MICROELECTRONICS INDUSTRY IN FRANCE

In 1960 the total output of microelectronic products in France was valued at less than $20 million. By 1977, the microelectronics product market in France was estimated at $130 million; by 1980, it had reached about $200 million, and estimates indicate a market of about $720 million in 1988.

In the initial phase of French microelectronic industry development, from the early 1960's to 1977, the industry was managed by France's private sector. On 23 May 1977 the French government essentially took over the management of the microelectronics sector in France (see Chapter 8).

Microelectronic product manufacture in 1977 was undertaken by the following seven French firms:

a) Thomson CSF (SESCOSEM Division);

b) EFCIS (Society of Studies and Manufacture of Special Integrated Circuits - a subsidiary of the Atomic Energy Commission with a minority holding by Thomson CSF);

c) LTT (Lignes Telegraphiques et Telephoniques - subsidiary of Thomas CSF);

d) RTC (Radio Technique Compelec - subsidiary (55 percent) of Philips);

e) Texas Instruments France;

f) SFS-ATES; and

g) Motorola Semiconductors France.

In 1977 the production from the indigenous companies accounted for less than 50 percent of the French market. Under the administrative leadership of the Counseil Economique et Social, established on 23 May 1977, negotiations took place between the French microelectronic industry and foreign companies based in France. The foreign firms were asked to operate under several government administrated plans, such as "mission pour les circuits integres" established during the second quarter of 1977 by the director of the Direction des Industries Electroniques et L'Informatique (DIELI/DGI) and the Direction des Affairs Industrielle et Internationales (DAII/DGI).

As discussed in Chapter 8, the French microelectronics industry did not do well under government plans and leadership. Nor did it do well under President Mitterand who "restored" the private sector role in the French microelectronics sector. In 1987, the last year for which information is available, production from indigenous companies accounted for less than 50 percent of the French market.

5.9 MICROELECTRONICS INDUSTRY IN GERMANY

In 1960, microelectronic product output in Germany was estimated at less than $10 million. In 1970, output had increased to an estimated $100 million. In 1981 it was estimated to be slightly in excess of $200 million, of which AEG-Telefunken contributed $40 million and Siemens, $155 million, and in 1988 the respective figure was $410 million.

The technology and manufacture of the German microelectronic sector is relatively basic and there is ample evidence that German microelectronic firms have consistently attempted to acquire U.S. and Japanese microelectronic technology (SHC, 1984). Siemens, for example, owns interests in five U.S. semiconductor companies, and AEG-Telefunken has interests in three U.S. companies. In spite of this infusion of foreign and advanced technology, the German microelectronics sector plays only a marginal role in the world's microelectronic markets.

5.10 MICROELECTRONICS INDUSTRY IN THE UNITED KINGDOM

The total annual output of microelectronic devices in the U.K. manufactured by British and foreign firms located in the U.K. is modest. Some measure of the relatively small contribution of the microelectronic sector in the U.K. can be seen from the fact that in 1987 this sector, comprised of native and foreign firms located in the U.K., accounted for only 6.5 percent of U.K. manufactured output. Corresponding figures for Japan and the U.S. were 12.5 percent and 19.5 percent respectively. If only native U.K. firms are counted, the U.K. native microelectronics sector in 1987 accounted for less than two percent of total manufactured output in the U.K.

In 1960 the output of microelectronic devices in the U.K. manufactured by native U.K. enterprises was valued at less than $1 million. The corresponding figure for the year 1970 was $127 million, and for the year 1975 - $168 million. In 1980 the output of microelectronic products in the U.K. was valued at $211 million, and in 1988 it was estimated at $330 million (Table 5.18). There are five principal native microelectronic product firms in the U.K.:

a) Marconi,

b) Plessey,

c) Standard Telephone Ltd.,

d) Ferranti, and

e) Inmos.

Plessey, Ferranti, and Inmos have on average, an output of about $100 million per year. Standard Telephone Ltd. is much smaller with average annual shipments valued at about $20 to $30 million. A total of about 40 foreign firms (U.S. and Japanese) have manufacturing facilities in the U.K.

TABLE 5.18

Production and Consumption of Microelectronic Devices in the United Kingdom, 1960-1988 (in millions of current dollars)

YEAR	PRODUCTION
1960	$ 1
1965	NA
1970	127
1975	168
1980	211
1981	220
1982	220
1983	238
1984	273
1985	299
1986	305
1987	315
1988	330

Source: SHC, 1988.

5.10.1 Foreign Firms in the U.K.

Whereas the native microelectronic sector in the U.K. has had relatively modest growth and does not represent a major supplier in the worlds microelectronic market, the U.K. has become a very attractive location for foreign microelectronic firms. As of early 1988, a total of some 480 foreign microelectronic firms were located in the U.K. (SHC, 1985).

There are three principal concentrations of foreign micro-electronic firms in the U.K.: the M4 Corridor located from West London along the M4 motorway to Bristol and South Wales; the "Silicon Ten" or the "Cambridge Phenomenon" located in the vicinity of Cambridge University; and the Silicon Glen, a corridor across Scotland bounded by Edinburgh, Dundee, and Greenock (Haug, 1986 and Dickson, 1987).

The reasons for the influx of foreign microelectronic firms into the U.K. are several, but essentially these may be described as the availability of services provided by the well developed British industrial infrastructure, the supply of well trained labour, and proximity to major European markets.

There are a number of reasons for the selection of these three particular areas within the U.K. as the centres of micro-electronic activity (Chandler, 1980; Dickson and Marsh 1978;

Burns, 1984). The most important of these reasons are: the presence of major academic resources (i.e. Cambridge University or the Microelectronics Institute at Edinburgh University); environmental, cultural, and related amenities at these locations; and local government subsidies for development (e.g. the Scottish Development Agency's Regional Development Grants).

As of Spring 1988, "Silicon Ten" contained about 340 advanced technology firms, of which about 260 undertake activities related to microelectronics; the corresponding figure for Silicon Glen was 210 firms, and for the M4 Corridor, about 150 firms. Among the firms located in these three areas are most of the largest U.S. and Japanese microelectronic enterprises as shown in Table 2.19.

The importance of these foreign owned microelectronic facilities located in the U.K. goes far beyond employment opportunities and wages.(3) One of the most important outcomes is the accelerated transfer of advanced microelectronic technology from the U.S. and Japan to the U.K. Equally important is the fact that the presence of such a large number of microelectronic firms in an area provides an opportunity for other related enterprises to be established to provide services to the existing microelectronic firms or undertake research, development, engineering and manufacture of other advanced technology products.

TABLE 5.19

Selected Major Microelectronic Firms Located in Scotland's Silicon Glen, 1988

COMPANY	TECHNOLOGY AND PRODUCTS	PRODUCTION STATUS	INVESTMENT	COMMENTS
Motorola East Kilbride (U.S.)	MPUs, Memory Custom NMOS,CMOS HMOS	On-Line	$150 million	Plant Size 250K sq ft; 100-125mm WAFERS, 2.5 GEOMETRY
National Semiconductor Greenock (U.S.)	Linear, MPUs Memory, Custom Bipolar, NMOS	On-Line	$148 million	Plant Size 300K sq ft; 100-125mm WAFERS, 2 GEOMETRY
NEC Livingston (Japanese)	Memory, MPUs, NMOS	On-Line	$100 million	Plant Size 180K sq ft; 125mm WAFERS, 3 GEOMETRY
Hughes Solid State Glenrowthes (U.S.)	Custom PMOS,NMOS CMOS,SOS	On-Line	$15 million	Plant Size 92K sq ft; 100-125mm WAFERS, 3 GEOMETRY Wholly-owned Subsidiary
General Instrument Glenrowthes (U.S.)	Memory, Custom Gate Arrays Semicustom NMOS,CMOS	On-Line	$105 million	Plant Size 80K sq ft; 100-125mm WAFERS, 3 GEOMETRY
Burr-Brown Livingston	Custom CMOS	On-Line	$60 million	Plant Size 75K sq ft
Integrated Power Semi-conductors Livingston (US)	Standard Bipolar Parts Custom and Semi-custom Power ICs	On-Line	$68 million	Plant Size 40K sq ft

Source: SHC, 1988.

Indeed, such developments have taken place. For example, as early as 1970 former employees of Motorola in Silicon Glen established Fortronics Ltd., which in 1988 employed over 170. In 1980 former employees of National Semiconductor established Rodime Ltd., a manufacturer of advanced computer disks, and in 1983 a firm (Lattice Logic Ltd.) was established in Edinburgh which offers one of the most advanced microelectronic device designs available (Haug, 1987).

5.11 MICROELECTRONICS INDUSTRY IN THE UNITED STATES

U.S. firms have dominated the microelectronic industry from its very inception in technological advances, manufacturing processes, and sales. They are expected to continue to remain a major supplier of microelectronic devices, but other nations will become an important factor in world markets. In 1967 about 68 percent of the total value of worldwide semiconductor output was manufactured by U.S. firms. By 1988 the U.S. share (including U.S. owned firms located off-shore) had declined, and according to the SIA, about 45 percent of the total world production in 1988 was manufactured by U.S. firms. The decreasing U.S. share points to growth in the worldwide markets of microelectronic device production by other nations, notably Japan and the NICs.(5)

Table 2.20 identifies the recent trends in microelectronic device consumption in the U.S. The consumption of all semiconduc-

TABLE 5.20

Trends in Microelectronic Device Consumption, United States, 1978 - 1988 (millions of current dollars)

MICROELECTRONIC DEVICES	1978	1980	1985	1988
Total Semiconductor	3,506	6,053	9,607	15,186
Total Integrated Circuits	2,335	4,562	7,710	12,664
Linear Circuits	570	709	1,457	2,085
Total Discrete Devices	1,005	1,289	1,528	1,970
Total Optoelectronic Devices	166	202	369	552

Source: SAI printouts, 1988.

tor devices in the U.S. in 1988 was estimated at $15.2 billion, an almost five-fold increase over 1978 estimates of $3.5 billion. Consumption of integrated circuits in the U.S. in 1988 was estimated at $12.7 billion, an almost six-fold increase over the corresponding figure for 1978 of $2.3 billion. Equally large increases in consumption can be seen for all other types of microelectronic devices.

For most advanced microelectronic product lines, such as microcomputers and microprocessors, U.S. industry is one of the principal sources in the world. U.S. firms also dominate the market for microelectronic product manufacturing equipment, and U.S.-designed and built microelectronic product processing equipment is used by all nations which have a native semiconductor industry. One consequence of this dominance, though, is that U.S. technological advances are diffused among most industrialized countries via the U.S. export of semiconductor manufacturing equipment.

5.11.1 U.S. Owned Facilities Located Abroad

Essentially, all major U.S. firms currently have production facilities in countries throughout the world. This movement towards foreign based production by U.S. firms has its roots in competitive survival and the changing economics of the industry. Starting in the late 1960's, the movement to locate microelectronic facilities abroad by U.S. firms consisted almost exclusively of so-called "back-end" operations comprising microelectronic product assembly. These operations were, and are, labour (but not skilled labour) intensive, and therefore U.S. firms had an enormous incentive to take advantage of the relatively inexpensive labour force in several less developed countries. In the early 1970's, the tendency for U.S. firms to establish production facilities abroad was accelerated, but for entirely different reasons. By then, U.S. firms recognized that the international market for microelectronic products was best served by manufacturing establishments located in those countries which consumed such products.

Unlike the early phase when only back-end operations were emphasized, U.S. firms are now establishing foreign microelectronic operations capable of undertaking the entire manufacturing process as well as research, development and engineering. Furthermore, in contrast to the earlier operations in less developed nations with low labour costs, U.S. firms have now established production facilities in such industrialized nations as Japan, France, the U.K., Italy, Germany, and other countries where significant markets exist for microelectronic products.

Foreign facilities have become almost indispensable to the U.S. industry. Foreign production currently accounts for 30 to 50 percent of the total output of many U.S. firms, and for some product lines this proportion is much higher.[6] It is agreed by most industry observers that U.S. firms have in the past expanded their operations overseas and will continue to do so in the future. (SHC, 1988; SIA, 1987). Most U.S.-based firms now manufacture some of the most advanced microelectronic devices abroad. Some of these advanced items find their way back to the U.S. For example, the IBM semiconductor facility in Japan is the major manufacturer and supplier of 64K RAMs required by IBM operations in the U.S. (Gutmanis, 1986).

5.11.2 Foreign Investment in the U.S. Microelectronics Industry

Over 50 foreign firms have either acquired, merged with, or otherwise increased their equity in U.S. owned firms since 1970.(7) This increased foreign investment in the U.S. microelectronics industry parallels the worldwide internationalization of the entire industry. As shown in Table 5.21, foreign interests have invested over $500 million in acquisitions of U.S. assets.

These developments have taken place since 1970. In 1969, there was no foreign ownership of U.S. microelectronics firms. Even by 1976, foreign ownership was very small with less than 10 percent of microelectronic products in the U.S. manufactured by foreign firms. By 1978, about 17 percent of total U.S. microelectronic product manufacture was owned by foreign firms (SIA, 1987), and by 1988, the figure was about 30 percent (SHC, 1988).

TABLE 5.21

Total Foreign Investment in the U.S. Microelectronics Industry, 1969 to 1988

INVESTOR	INVESTMENT ($ Million)	PERCENT of total
United Kingdom	9.6	1.9
Bahamas	10.0	1.9
Canada	11.2	2.2
Japan	16.1	3.1
Netherlands	43.9	8.5
West Germany	61.7	12.0
France	363.0	70.4
TOTAL	515.3	100.0

SOURCE: ITC, Competitive Factors Influencing World Trade in Integrated Circuits, 1985 and ITA printouts, 1988.

Many of these foreign firms manufacture in their U.S. facilities the most advanced microelectronic devices. For example, the three major Japanese firms which have manufacturing facilities in the U.S. are currently producing memory devices in these facilities. The firms are Hitachi Ltd.; Fujitsu Microelectronics Inc., in Santa Clara, California; and NEC Electronics (USA) Inc., in Mountainview, California. This expansion of foreign-based facilities in the United States represents an obvious and further dimension in the trend towards the internationalization of the world microelectronics industry.

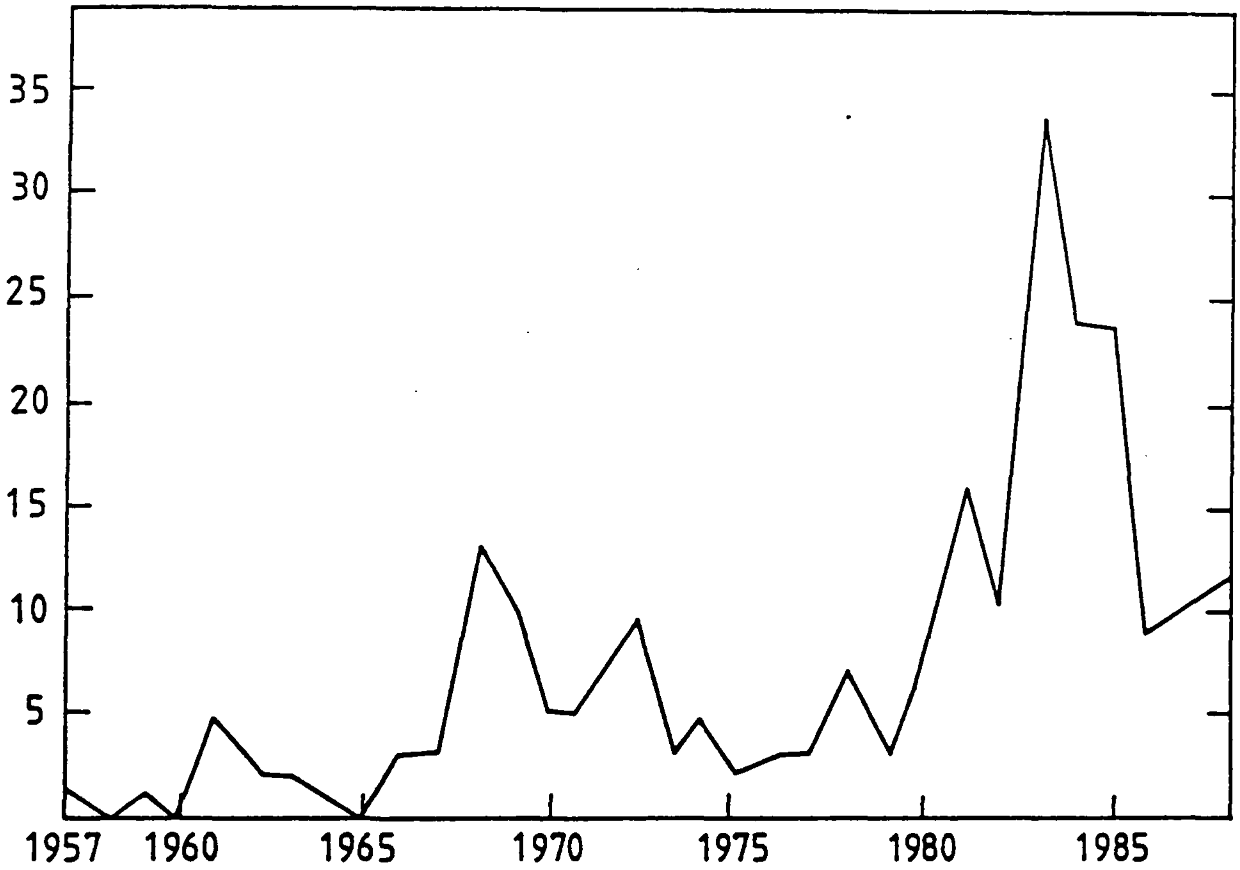
5.11.3 Number of Microelectronic Firms

The number of U.S.-based firms manufacturing microelectronic products declined from about 120 in 1972 to approximately 100 in 1980, only to increase to 230 in 1988 (Figure 5.7).

As shown in Figure 5.7, the entry rate accelerated in the early 1960's and again from 1968 to 1971, so that the average annual number of new firms from 1960 to 1972 was 4.69, as compared to 2.78 in the 1950's. Yet despite rapid market growth after 1975, only four new firms entered the industry during the 1973-78 period, a rate of just 0.67 per year. During the 1986 to 1988 period, a total of 120 new firms were established although the annual number of new entrants after 1984 declined rapidly. Business Week reports:

Figure 5.7

World Wide Formation of New Micro-
electronic Firms, 1957 - 1987



Source: Derived from Dataquest, January issues, 1960 to 1988.

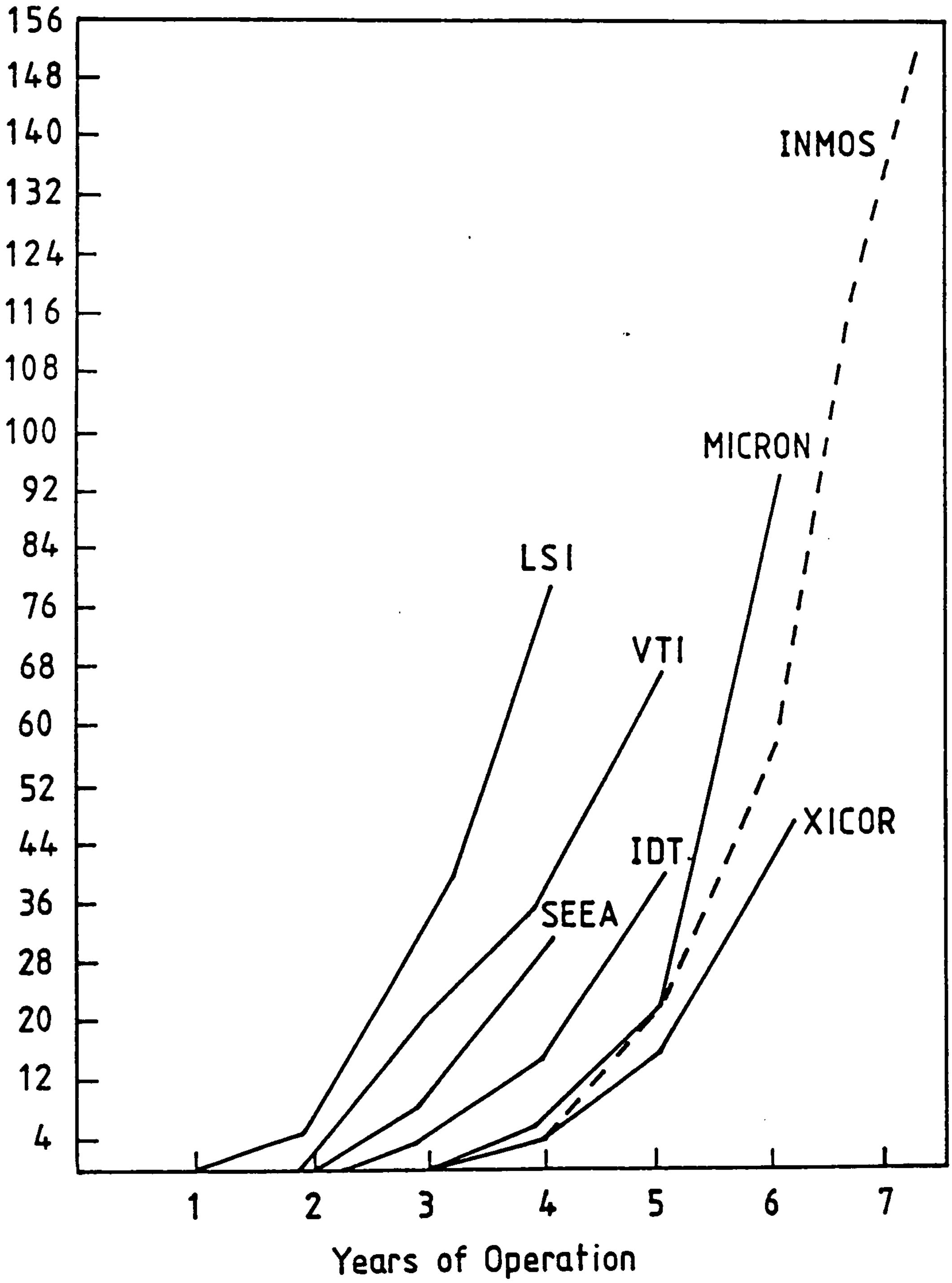
> Venture capital is flowing into start-ups at the rate of an estimated $250 million in 1980, up from just $20 million as late as 1975, and has helped drain key people from not only semiconductor makers but also makers of computers, video games, and other equipment.
>
> The pressure shows no sign of easing. In fact, the flow of venture dollars is still growing. Stanley E. Pratt, editor of Venture Capital Journal, predicts that $300 million will be plowed into new ventures by the end of this year, up 20%. (Business Week, 8/24/87)

Indeed, the avilability of large amounts of venture capital in the 1980's has resulted in a large number of new entrants into the industry. A significant number of microelectronics firms established in the U.S. during the last decade have achieved considerable sales volumes in a period of six years or less, as shown in Figure 5.8.

These new entrants in the microelectronic sector are unique in that most are speciality firms manufacturing microelectronic products for narrow or "niche" markets. As such, these firms do not offer competition to the Japanese, but in fact compete with smaller firms in EC countries and to a certain extent with firms in NIC countries. The sales volume of these firms is modest. More importantly, research and development activities by these firms are narrow and directed at prescribed applications of microelectronic devices. It is not likely that these firms will offer significant advancements in microelectronic technologies.

Figure 5.8

Sales Volume Over Time of Selected Microelectronic Firms Established Since 1978, United States (in millions of current dollars)



Source: ICE, 1988.

5.12 MICROELECTRONICS INDUSTRY IN JAPAN

The structure of the Japanese industry differs from that of the U.S. As reported by the SIA:

> The Japanese semiconductor industry evolved in a different way than the American. As summarized by an executive of a Japanese firm, the Japanese semiconductor industry is mostly formed by large electronics system companies, especially communications and computer equipment makers, and home electronic makers, all of which started semiconductor device development soon after the transistor was invented and steadily invested resources to develop the new technology and market. In addition to these long standing semiconductor makers, watch-makers, automobile electric component makers and desk top calculator makers are joining in the semiconductor industry. Hence, the Japanese semiconductor industry is closely integrated in the business system within its own organizations and long standing inter-business relations. These are distinct characteristics of the Japanese semiconductor industry, and have heavily influenced their technological developments (SIA, 1983).

While the SIA characterization of the Japanese industry is essentially correct, it fails to underscore the unique features of this industry which, to a significant degree, govern the Japanese market for microelectronic products in Japan. The principal unique feature is that all Japanese microelectronic firms are vertically integrated systems which manufacture various products exclusively for their own end-product use in Japan. Thus all Japanese microelectronic product manufacturers are essentially departments within a Japanese firm which supply their products to other departments for use in end-products.

The competition among the Japanese firms in terms of sales of their electronic end-products in Japan as well as in export markets, is exceptionally fierce. As a result, microelectronic departments in vertically integrated Japanese firms have a well established practice of providing substantial custom service in the design, quality and delivery of their products to the other departments within their firms.

Of course, in addition to manufacturing microelectronic products for their own end-products, the Japanese microelectronic product departments export a portion of their products to other countries, including the U.S. and EC nations, and therefore compete with U.S. merchant and EC microelectronic firms. Here again, due to their well established practice of providing substantial custom service to their own intra-firm departments the Japanese can and do provide similar quality service in their export markets.

Anyone even marginally familiar with the history of the telecommunications industry in the U.S. will not fail to recognize that the Japanese electronic industry's structure resembles the historical relationship between AT&T and Western Electric. This is not a coincidence. Shortly after the conclusion of the hostilities of World War II, the U.S. occupation forces requested that AT&T furnish management assistance to the Japanese Telecommunications Ministry with regard to procurement procedures and supply systems. AT&T recommended that NTT develop a system whereby designated suppliers (principally NEC), working closely and almost exclusively with NTT, provide tailor-made goods and services, which in turn would provide for the efficient production of goods of very high quality (Zahm, 1951). Ever since then, all other Japanese electronics firms have established this type of industry structure.

Japanese microelectronic product output in 1978 was $2.4 billion; in 1985 it was $8.6 billion; and in 1988 it was over $12 billion. Not only have the Japanese rapidly expanded international sales of microelectronic products, but also Japanese consumption of such products has increased equally as rapidly. As the data in Table 5.22 show, Japanese consumption of all microelectronic products has increased by a factor of almost eight over the last decade. For total integrated circuits the increase was even higher, with consumption increasing from $1.4 billion in 1978 to $13.6 billion in 1988.

The Japanese industry was able to meet the rapidly growing domestic demand for microelectronic products as well as produce for world markets because of increasing capacity, a direct result of very large capital expenditures, which have more than doubled during the 1979 to 1988 period (Table 5.23).

TABLE 5.22

Trends in Microelectronic Device Consumption, Japan, 1978 - 1988 (millions of current dollars)

MICROELECTRONIC DEVICES	1978	1980	1985	1988
Total Semiconductor	2,448	3,383	8,599	17,347
Total Integrated Circuits	1,399	2,201	6,567	13,576
Linear Circuits	552	865	2,019	3,824
Total Discrete Devices	946	986	1,566	2,764
Total Optoelectronic Devices	103	196	466	822

Source: SIA printouts, 1988.

TABLE 5.23

Japanese Microelectronics Firm Capital
Spending, 1979 - 1988
(in millions of current dollars)

COMPANY	1979	1985	1988
Nippon Electric	115	127	165
Hitachi	64	98	122
Fujitsu	68	110	145
Matsushita	43	72	110
Toshiba	43	81	97
Oki Electric	23	68	81
Mitsubishi	34	60	67
Sony	21	55	60
Tokyo Sanyo	18	19	25
Sharp	37	43	61
Fuji Electric	8	15	20
TOTAL	474	648	953

Source: Japan Economic Journal, January 1980, 1987 and 1989.

These very large capital expenditures by Japanese firms (which for some -- i.e., Sony -- reached 36 percent of total sales) allowed the Japanese to build microelectronic production faciltities and keep pace with rapidly advancing production technologies. Japanese government policies were designed to satisfy the large capital needs of Japanese microelectronic firms (see Chapter 12).

5.12.1 Japanese Foreign Operations

The Japanese microelectronics industry consists of vertically integrated multi-product firms with very extensive relationships among various suppliers of goods and services to these firms. As a result of these linkages, and due to the unique relations between management and labour in Japan, Japanese microelectronics firms operated, until the mid-1970's, almost exclusively on their own soil. Unlike microelectronic firms in the U.S., Japanese enterprises did not seek off-shore facilities in the first decade or so of microelectronic product manufacture (Yoshino, 1975).

The increasing labour costs in Japan and the need to be in the proximity of overseas markets, forced Japanese firms to establish overseas facilities starting in the mid-1970's. Table 5.24 presents a listing of major Japanese microelectronic facilities located in the U.S. and Europe.

Thus, the Japanese microelectronic industry has undertaken measures leading to the international dispersion of their industry, similar to that of the U.S., but at a later date and only after Japanese firms had overcome their early development period and had grown to a substantial size from domestic sales. The growth of Japanese firms on the basis of domestic and protected markets allowed these firms to take advantage of economies of scale. Simply put, the Japanese microelectronic industry followed explicitly Krugman's 1983 theory of comparative advantage in international trade.

5.13 SUMMARY

The value of world-wide production of microelectronic devices has increased from about $2.3 billion in 1967 to over $47 billion in 1988, and is expected to exceed $130 billion in 1995. The microelectronic industry has become increasingly international although the U.S. and Japan have dominated world markets for microelectronic products throughout the thirty year history of the industry.

The U.S. invented the initial microelectronic products, as well as manufacturing processes, and because of its comparetive advantage in many scientific and advanced technology fields, maintained superiority in the first two decades of the micro-electronic industry in product design, technological advance, and

TABLE 5.24

Major Japanese Microelectronic Facilities in the U.S. and Europe, 1988

COMPANY	LOCATION	ASSEMBLY	FABRICATION	COMMENTS
Fujitsu Micro- electronics, Inc.	San Diego,CA	64K,256K DRAM; 16K SRAM; 16K, 32K, 64K EPROM		Established 1980
	Santa Clara, CA			Gate Array Design Centre Established 1980
	Boston, MA			Established 1982
	Dallas, TX			Established 1982
	Chicago, IL			Established 1983
	Minneapolis, MN			Established 1983
	Atlanta, GA			Established 1983
	Portland, OR		High-Density MOS Memory	
Fujitsu	Tallaght, Ireland	16K,64K DRAM		Established 1981
Hitachi Semicon- ductor (America) Inc.	Irving, TX	16K,64K,256K DRAM;4K,16K SRAM	Planned to Begin in 1985	Established 1978 Total IC Output about 1 Million Units per Month.
(Europe), GmbH	Landshut, West Germany	16K DRAM, 16K SRAM		Established 1982
NEC Electro- nics,Inc.	Mountain View, CA	16K,64K,256K DRAM; 32K,64K EPROM		Established 1978 Total Output approx. 2 Mill. Units per Month
	Roseville, CA	Assemble all Devices Fabri- cated at Roseville	64K,256K DRAM; ROM; Gate Arrays Custom MPUs	Established 1984. Maximum Capacity 90,000 Wafers per Month

TABLE 5.24 (cont.)

OMPANY	LOCATION	ASSEMBLY	FABRICATION	COMMENTS
	Livingston, Scotland	8 Bit,16 Bit MPU; 64K SRAM 64K,256K DRAM		Established 1983 Wafer Fab. 1985, 6" Wafers. Potential Capacity by 1987 6 Mill. per Month
	Ballivor, Ireland	16K,64K DRAM		Established 1974
	Sunnyvale, CA			Gate Array Design Centre
	Dusseldorf, West Germany			Gate Array Estab. 1983
	Hong Kong			Design Centre
oshiba emiconductor USA), Inc.	Sunnyvale, CA	NMOS, CMOS, 16K SRAM, DRAMs; 16K, 64K DRAM; MPUs	16K SRAM, 8 Bit MPUs	Established 1980 Total Output approx. 2.5 Mill. Units per Month in RAMs
Europe) GmbH	Braunschweig, West Germany	CMOS, NMOS, 16K SRAM; 1984-64K SRAM 64K DRAM. Gate Arrays, MPUs		Established 1983. Total Output about 1 Mill. Units per Month.

ource: SHC, 1988.

production. Japan, which was not a significant factor in microelectronics during the early years of this industry, systematically improved its comparative advantage in microelectronics and, by the year 1986, surpassed the U.S. Much of the microelectronic industry's growth in Japan may be explained by the Japanese science, technology, and industrial policies, directed by the Japanese government. An important component of Japanese policies has been the Japanese government's financial support for capital investment in the microelectronic industry. Microelectronic technology has advanced at a very rapid rate, and this advancement has, in turn, required increasingly larger expenditures for research and development as well as for microelectronic product manufacturing facilities. Japanese microelectronic producers have been able to keep up with the advanced technology in microelectronics by obtaining the required information from the U.S., by purchasing the required technologies, or by using other vehicles of international technology transfers such as cross-licensing or co-production.

Japanese microelectronic firms surpassed those of the U.S. in capital expenditures by simply spending more, and at a faster rate for the equipment, machinery, and instrumentation used in microelectronic product manufacture. The policies of the Japanese government allowed, even encouraged, Japanese firms to undertake large capital expenditures, whereas the market structure and government policies in the U.S. curtailed such expenditures by

U.S. firms. The result of these trends has been the emergence of Japan not only as the world's leading microelectronic device producer, but also as the dominant supplier of equipment and machinery used in product manufacture.

European nations and some NIC's (principally Korea, Singapore, and Brazil) have also increased their microelectronic product output, but clearly are not an important source for such products.

It is also very likely that EC countries and other nations will remain relatively minor suppliers of microelectronic devices in the future. There are several reasons for this. These include the Japanese large scale production capacity of microelectronic products, and therefore the ability to sell these products at low prices; the continuing demand for additional and increasingly larger capital expenditures brought about by advances in production technology; and the rapid obsolescence of microelectronic, products with new devices replacing existing products within relatively short time periods.

The future of the microelectronics industry in the U.S. is not certain. Clearly the U.S. has lost its lead and comparative advantage to Japan. Whether or not the U.S. can maintain its precent share in the world market for microelectronic products depends on the policies of U.S. microelectronics firms as well as the policies of the U.S. government.

Past changes in the world's microelectronic industry represent an almost ideal case study of the neotechnological theory of international trade formulated by Hufbauer (1970) and others (Gruber, Mechta, Vernon, 1964), and a rejection of the classical international trade theories. Japanese governmental policies to overcome the initial comparative advantage in microelectronic device production held by the U.S. are explored in detail by Krugman (1979, 1983, 1984). Chapter 12 discusses these issues in detail.

FOOTNOTES TO CHAPTER 5

1. This so called "learning curve" effect stipulates that increases in volume of production will result in decreasing unit production costs. For the microelectronics industry, this relationship is referred to as "Moore's Law" after the chairman of Intel Corporation who postulated one-half reduction in unit manufacturing costs for every two-fold increase in commulative production of microelectronic devices. See: Robert N. Noyce, "Microelectronics", in Tom Forester, ed., The Microelectronics Revolution, Cambridge, MA: MIT Press, 1981.

2. The Economist (July 1, 1989) reports that projection of capital spending in the microelectronics industry by region in 1993 will almost double 1988 spending. The projections are as follows: for Japan over $10 billion; for the U.S. $6.2 billion; for EC countries $2.2 billion; and for the rest of the world $2.0 billion.

3. The listing below identifies principal international agreements in microelectronic production by country and firm from 1971 to 1988.

COMPANY	NUMBER OF AGREEMENTS	NUMBER OF PARTNERS	PARTNERS	YEAR OF AGREEMENT
UNITED STATES				
AMD	4	4	Goldstar	1984
			Siemens	1984
			Signetics/Philips	1981
			Thomson-CSF	ND
American Microsystems Inc.	4	4	Asani	1983
			Hitachi	1984
			NEC	1983
			Voset-Alpine	1981
Fairchild (Cross-listed here and in "Europe")	7	7	GEC	1978
			Goldstar	1984
			Hitachi	1982
			National Semi-conductor	1982
			Philips	1982
			Sanyo	1981
			VLSI	1981
Harris	1	1	Matra	1980
Intel	14	9	Fujitsu	1981
			Fujitsu	1984
			Fujitsu	1984
			Matra-Harris	1981
			Mitsubishi	1981
			NEC	1981
			NEC	1982
			Oki	1981
			Oki	1984
			Philips	1982
			Samsung	1984
			Sanyo	1983
			Siemens	1982
			Siemens	1984
LSI, Logic	3	3	Goldstar	1984
			SGS-Ates	1980
			Toshiba	1982

COMPANY	NUMBER OF AGREEMENTS	NUMBER OF PARTNERS	PARTNERS	YEAR OF AGREEMENT
UNITED STATES (cont.)				
Mostex	2	1	AEG-Telefunken	1983
			AEG-Telefunken	1984
Motorola	8	6	Hitachi	1981
			Hitachi	1984
			Philips/Signetics	1981
			Sagem	ND
			Thomson-CSF	1981
			Thomson-CSF	1984
			Toko	1984
			Toshiba	1984
National Semiconductor	4	4	Fairchild	1982
			Oki	1983
			Samsung	1984
			Thomson-CSF	1983
RCA	4	4	Hitachi	ND
			Philips	1982
			Sharp	1984
			Toshiba	1980
Signetics	3	3	AMD	1981
			Motorola	1981
			Texas Instruments	1984
Standard Microsystems	5	5	Fujitsu	1982
			Hitachi	1981
			NEC	ND
			Oki	1984
			Toshiba	1983
Texas Instruments	5	5	Fujitsu	1984
			Goldstar	1984
			Hyundai	1984
			Philips/Signetics	1984
			Thomson-CSF	1981
Zilog	8	7	Goldstar	1984
			NEC	1983
			NEC	1984
			Olivetti	1980
			SGS-Ates	1981
			Sharp	1981
			Siemens	1981
			Toshiba	1982

COMPANY	NUMBER OF AGREEMENTS	NUMBER OF PARTNERS	PARTNERS	YEAR OF AGREEMENT
JAPAN				ND
Fujitsu	8	6	Amdahl	NS
			ICL	1981
			Intel	1981
			Intel	1984
			Intel	1984
			Monolithic Memories	1984
			Standard Microsystems	1982
			Texas Instruments	1984
Hitachi	9	8	AMI	1984
			Fairchild	1982
			Hewlett Packard	1982
			Microcircuit Engr.	1982
			Motorola	1981
			Motorola	1984
			National Advanced Systems	ND
			RCA	ND
			Standard Microsystems	ND
Matsushita	1	1	IBM	ND
Mitsubishi	3	3	Intel	1981
			Sperry	1982
			Stanford Applied Engineering	1983
NEC	12	9	AMI	1983
			Corvus Systems	1984
			Digital Research	1984
			Hewlett Packard	1984
			Intel	1981
			Intel	1982
			Matra-Harris	ND
			Standard Microsystems	1983
			Tektronix	1983
			Tektronix	1984
			Zilog	1983
			Zilog	1984
Oki	5	4	Intel	1981
			Intel	1984
			National Semiconductor	1983
			Standard Microsystems	1984
			Thomson-CSF	1984

COMPANY	NUMBER OF AGREEMENTS	NUMBER OF PARTNERS	PARTNERS	YEAR OF AGREEMENT
JAPAN (cont.)				
Ricoh	5	5	Custom MOS Arrays	1984
			IXYS	1984
			Panatec R&D	1984
			Rockwell	1982
			VLSI	1983
Sanyo	2	2	Fairchild	1981
			Intel	1983
Sharp	6	6	Energy Conversion Devices & Burroughs	1979
			RCA	1984
			Rockwell	1982
			Samsung	1984
			Wafer Scale Integration	1984
			Zilog	1981
Toshiba	9	7	Korea Electronics	1978
			Korea Electronics	1983
			LSI Logic	1982
			Motorola	1984
			RCA	1980
			SGS-Ates	1981
			SGS-Ates	1984
			Standard Microsystems	1983
			Zilog	1982
EUROPE				
GERMANY				
AEG-Telefunken	2	1	Mostek	1982
			Mostek	1983
Nixdorf	1	1	Ferranti	1981
Siemens	7	5	AMD	1984
			Fuji	ND
			Intel	1982
			Intel	1984
			Philips	1982
			Philips	1984
			Zilog	1981

COMPANY	NUMBER OF AGREEMENTS	NUMBER OF PARTNERS	PARTNERS	YEAR OF AGREEMENT
FRANCE				
Bull	1	1	Trilogy	1982
Matra	6	6	Citel	1983
			GCA	1982
			Harris	1980
			Intel	1981
			NEC	ND
			Tandy	1981
Thomson-CSF	5	4	AMD	ND
			General Instrument Microelectronics	ND
			Motorola	1981
			Motorola	1984
			Oki	1984
ITALY				
Olivetti	4	4	Goldstar	1984
			Linear Technology	1982
			VLSI	ND
			Zilog	1980
SGS-Ates	5	4	IBM	1983
			LSI Logic	1980
			Toshiba	1981
			Toshiba	1984
			Zilog	1981
NETHERLANDS				
N.V. Philips	8	7	AMD	1981
			Fairchild	1982
			Intel	1982
			Motorola	1981
			RCA	1982
			Siemens	1982
			Siemens	1984
			Texas Instruments	1984

COMPANY	NUMBER OF AGREEMENTS	NUMBER OF PARTNERS	PARTNERS	YEAR OF AGREEMENT
UNITED KINGDOM				
GEC	2	2	Fairchild	1978
			Mitel	ND
Ferranti	3	3	GTE	1982
			Hong Kong Semi-conductor Devices	1983
			Nixdorf	1981
ICL	1	1	Fujitsu	1981
Inmos	2	2	Hyundai	1984
			NMB Semiconductor	1984
SOUTH KOREA				
Goldstar	7	7	AMD	1984
			ATT	1984
			Fairchild	1984
			LSI, Logic	1984
			Texas Instruments	1984
			Olivetti	1984
			Zilog	1984
Hyundai	4	4	Inmos	1984
			International CMOS Technology	1984
			Texas Instruments	1984
			Western Design Center	1984
Korean Electronics	2	1	Toshiba	1978
			Toshiba	1983
Samsung*	7	7	Exel Microelectronics	1984
			Intel	1984
			ITT	ND
			Micron Technology	1984
			National Semiconductor	1984
			Sharp	1984
			Zytrex	1984

*Includes Tristar

ND = No date.

Source: SHC, 1987.

The following is a summary as to the number of international agreements by country in the 1981 to 1988 period:

United States	-	72 international agreements
Japan	-	60 international agreements
Germany	-	10 international agreements
France	-	12 international agreements
Italy	-	10 international agreements
Netherlands	-	8 international agreements
The United Kingdom	-	8 international agreements
South Korea	-	10 international agreements

The number of partners for each country in the international agreements is proportional to the number of agreements made.

United States	-	63 partners
Japan	-	51 partners
Germany	-	7 partners
France	-	11 partners
Italy	-	8 partners
Netherlands	-	7 partners
The United Kingdom	-	8 partners
South Korea	-	8 partners

Most of the international agreements were made in the 1980 to 1985 period. During this five year period a total of 168 international agreements were concluded. In the nine year period from 1971 to 1980 only 27 agreements were made. Since 1985 no international agreements have been concluded.

Available information suggests that a significant number of U.S. and Japanese microelectronic firms will conclude international agreements with one or several firms located in Europe before 1992 in order to establish a presence in the Common Market. The following U.S., Japanese and South Korean firms were negotiating international agreements with European firms as of the end of 1989.

UNITED STATES

Harris - 2 agreements

LSI, Logic - 2 agreements

Motorola - 3 agreements

RCA - 3 agreements

Texas Instruments - 4 agreements

JAPAN

Fujitsu - 4 agreements

Hitachi - 3 agreements

Matsushita - 2 agreements

Mitsubishi - 3 agreements

NEC - 4 agreements

Oki - 2 agreements

Sanyo - 2 agreements

Sharp - 1 agreement

Toshiba - 4 agreements

SOUTH KOREA

Goldstar - 3 agreements

Samsung - 5 agreements

4. The reception of JESSI by the various European countries has been mixed. As reported in Science:

> "The existence of JESSI is a minimal precondition for the survival of the semiconductor industry in Europe," says Anton Heuberger of the Fraunhofer Institute for Microstructure Technology in Berlin, who chaired the team that produced the blueprint for JESSI. Heuberger points out that, even when added together, the turnover of Philips, Siemens, and SGS-Thomson, Europe's largest three chip-makers, still is smaller than that of the top three Japanese companies.
>
> Not all EEC member states see eye to eye on the need to provide large public subsidies to their semiconductor industries. Britain, for one, has been lukewarm. In contrast, JESSI has received enthusiastic support--and an immediate pledge of $22 million--from the West German government, which argues that such subsidies are justified by the current weak market position of European chip manufacturers. And last month, the European Commission agreed to provide substantial support--perhaps as much as 25% of the eventual costs. The Dutch, French, and Italian governments have also voted extra funds for JESSI research projects. ("Can Europe Survive on Chips?", Science, 21 July 1989, pp. 246).

5. The decline of the U.S. microelectronics industry was underscored on August 15, 1989 when a large U.S. microelectronics firm, the Materials Research Corporation (MRC), accepted a tender offer from Japan's Sony Corporation for $60 million, or less than half of MRC's annual sales rate. Business Week referred to this as "... bargain-basement shopping time for U.S. technology. Silicon Valley is watching its worst nightmare unfold" (Business Week, 4 September 1989, p. 63).

6. A listing of the principal U.S. microelectronics facilities located abroad are as follows:

TEXAS INSTRUMENTS

Germany	U.K.	Japan
France	Malaysia	Italy
Singapore	Mexico	Taiwan
Portugal	Argentina	Hong Kong
El Salvador		

INTERNATIONAL RECTIFIER CORP.

U.K.	Belgium	Italy
Germany	Canada	Mexico
The Netherlands		

INTEL CORPORATION

Malaysia	Philippines	Barbados
Israel	Mexico	Hong Kong

STANDARD MICROSYSTEMS CORPORATION

U.K.

SILICONIX, INC.

U.K.	Hong Kong	Taiwan

LITRONIX

Malaysia	Mauritius	Singapore
Germany	U.K.	

INTERSIL, INC.

Mexico	Singapore

UNITRODE

Mexico	Germany

ADVANCED MICRO DEVICES

Malaysia	Philippines

U.S. Offshore Facilities (cont.)

NATIONAL SEMICONDUCTOR CORPORATION

U.K.	Hong Kong	Malaysia
Indonesia	Singapore	South Korea
Australia	Thailand	Brazil
Philippines		

MOSTEK

Malaysia	Belgium	Philippines
Taiwan		

HARRIS

Canada	U.K.	France
Malaysia	Germany	

MOTOROLA

Australia	Canada	Costa Rica
Denmark	France	Hong Kong
Israel	Japan	South Korea
Malaysia	Mexico	Philippines
Puerto Rico	South Africa	Switzerland
U.K.	Germany	

HONEYWELL

Canada	Belgium	Italy
France	Germany	The Netherlands
Denmark	Spain	Austria
Sweden	Finland	Norway
Greece	Switzerland	U.K.
Japan	Kuwait	Saudi Arabia
Taiwan	Australia	New Zealand
Thailand	Hong Kong	Singapore
Venezuela	Mexico	Puerto Rico
	South Africa	United Arab Emirates

HEWLETT PACKARD

Brazil	U.K.	France
Japan	Malaysia	
Singapore	Germany	

U.S. Offshore Facilities (cont.)

IBM

Australia	Canada	France
U.K.	Bermuda	Austria
Belgium	Denmark	Finland
Madagascar	Germany	Ireland
Israel	Italy	Netherlands
Norway	Portugal	South Africa
Spain	Sweden	Switzerland
Turkey	Argentina	Bolivia
Brazil	Chile	Columbia
Costa Rica	Ecuador	Guatemala
Honduras	Uruguay	Venezuela
Hong Kong	Japan	South Korea
Mexico	New Zealand	Panama
Peru	Philippines	Singapore
Taiwan	Thailand	

SOURCE: SRC, 1988

The U.S. firms with the largest number of off-shore facilities are those which manufacture microelectronic products that are labor intensive. The following are the five U.S. microelectronic firms with the largest number of offshore facilities:

1. IBM
2. Honeywell
3. Texas Instruments
4 Motorola, and
5. National Semiconductor Corporation

7. The listing below presents foreign investments (acquisitions, mergers, and equity increases) in the U.S. microelectronics industry by foreign countries and firms.

COUNTRY	FOREIGN FIRM	U.S. FIRM	YEAR	PERCENT EQUITY	TRANS-ACTION COSTS ($M)
JAPAN	Nippon	Electronic Arrays	1978	100	8.9
	Mansei	Maruman Kogyo	1976	60	2.7
	Toshiba	Toshiba-America	1978	(new plant)	8.3
	Fujitsu	Amdahl	1976	29	68.0
	Tokyo Print Industry	Tokyo Print Industry	1976	(new plant)	3.0
	Mitsubishi	Optel	1975		2.5
	Sony	Sony Magnetic Products	na	(plant expansion)	12.0
	Toyo	Exar	1972	53	1.0
	Hitachi Ltd.	Hitachi S.C.	1978	(new plant)	0.5
	Daima (Seiko)	Micropower Systems	1971	77	3.4
	TDK	TDK Electronics	1978	(new plant)	50.0
GERMANY					
	Siemens	Microwave Semiconductor	1979		25.0
	Siemens	Orbis Systems	1979		3.5

COUNTRY	FOREIGN FIRM	U.S. FIRM	YEAR	PERCENT EQUITY	TRANS-ACTION COSTS ($M)
GERMANY (cont.)					
	VDOA Schindling	Solid State Scientific	1979	25	5.0
	Robert Bosch	Millenium Systems	1978		0.6
	Robert Bosch	American Microsystems	1977	12.5	14.2
	Siemens	Advanced Micro Devices	1977 1978	20 20	26.7 1.0
	Siemens	Litronix	1977	100	16.2
	AEG VTelefunken	AEG QPower	1978		0.3
	Siemens	Seimcus Corp.	1978		0.4
	Rosenthal	Metalized Ceramics	1977	100	5.3
	Mixdorf (with Fujitsu)	Amdahl	1972	5	1.0
	Ernst Bodenstein	Entron	1976		1.9
UNITED KINGDOM					
	National Enterprise Board	Inmos	1979		0.6
	Lucas Industries	Siliconix	1978	24	6.1
	Ferranti	Inter Design	1977	100	3.5
	English Electric Value	Microwave Associates	1977		1.0
	General Cable	Sprague Electric	1976	100	68.0

COUNTRY	FOREIGN FIRM	U.S. FIRM	YEAR	PERCENT EQUITY	TRANS-ACTION COSTS ($M)
UNITED KINGDOM (cont.)					
	EHI	Electronic Technology	1975		0.6
	General Electric Ltd.	Modular Computer Systems	1978		5.3
NETHERLANDS					
	Akze	General Circuits	1979		2.5
	Philips	G.E. Capacitor	1977	100	10.1
	Philips	Signetics	1975	100	43.9
	Philips	National Components Industries	1974	100	5.9
FRANCE					
	Thomson-Brandt	Solid State Scientific	1979	100	14.2
	Schlumberger	Fairchild	1979	100	363.0
	Schlumberger	Unitrode	1979	14	10.0
CANADA					
	Bell Telephone of Canada	Northern Telecom	1979		3.4
	Northern Telecom	Intersil	1977	24	10.9
	Bell Telephone of Canada	AVH	1979	100	0.6
	Northern Telecom	Monolithic Memories	1969	12	0.3
	C. Tech Ltd.	C. Tech.Ltd.	1979		0.4

SOURCE/ COUNTRY	FOREIGN FIRM	U.S. FIRM	YEAR	PERCENT EQUITY	TRANS-ACTION COSTS ($M)
SWITZERLAND					
	ASHAG Group	Slatek	1979		8.9
	Oberlikon-Bohric	Balzers	1979		1.0
	ASH	Centre Engineering	1977	100	2.7
BAHAMAS					
	Commodore	Frontier	1976	100	10.0
	Commodore	MOS Technology	1976	99	1.0
	Anglo Company	Printex Corp.	1974	100	1.9
GREECE	P. Group	Thermo Electron	1976	100	3.4
SWEDEN	Bofors	BAF Group	1976	100	15.0
HONG KONG	Hong Kong Investors	Supertex	1976	10	6.1

SOURCE: U.S. Department of Commerce, ITA, Foreign Investment in the United States, 1989.

Summary of the foreign investments in the U.S. microelectronics industry is as follows:

Japan	-	$91.4 million
Germany	-	$64.2 million
The United Kingdom	-	$78.2 million
Netherlands	-	$59.9 million
France	-	$373.0 million
Canada	-	$12.5 million
Bahamas	-	$12.9 million
Greece	-	$3.4 million
Sweden	-	$15.0 million

The very large French investment represents the outright purchase of the U.S. microelectronic firm Fairchild by the French firm Schlumberger.

The investments made by Japan, Germany, the United Kingdom and Netherlands were principally undertaken to obtain the advanced microelectronics technology from the U.S. firms. The initial investment by Japan, which consisted of the outright purchase of Electronic Arrays, was undertaken in 1978 to obtain advanced 16K-RAM technology, developed by Electronic Arrays.

Investment by Fujitsu in the U.S. Amdahl Corporation in 1976 was undertaken to obtain initial parallel data processing technology developed by Amdahl.

Siemens' investment in Advanced Micro Devices in 1977 and 1978 was undertaken to obtain the advanced semiconductor manufacturing technology developed by Advanced Micro Devices.

It is of some interest to note that most of these foreign investments took place in the 1970's, a time period when U.S. microelectronics technology was advancing at a rate considerably more rapid than technologies developed in Japan, Germany and the United Kingdom. Taking the U.S. microelectronic technology as 10, the following are the technology rankings for the other nations in 1975 (SHC, 1988):

Japan	-	7
Germany	-	4
The United Kingdom	-	3
France	-	3
Netherlands	-	3

In the year 1980 the technology rankings were as follows (SHC, 1988):

Japan	-	9
Germany	-	5
The United Kingdom	-	4
France	-	3
Netherlands	-	5

In the year 1985 the microelectronics technology in Japan had reached a level identical to that of the U.S. For the other European nations the technology rankings were as follows (SHC, 1988):

Germany	-	6
The United Kingdom	-	5
France	-	3
Netherlands	-	5

The investments by Canada and Sweden in the U.S. microelectronic industry were undertaken in order to assure an adequate supply of microelectronic products for Canadian and Swedish manufacturers.

The investments by Greece, Hong Kong, Switzerland and Bahamas were made by investor groups in these countries to gain a foothold in the (then) lucrative microelectronics industry of the U.S.

Foreign investments _per se_ in the U.S. microelectronics industry essentially ceased after 1980, because investments _per se_ were replaced by construction of new microelectronic manufacturing facilities funded by foreign entities established and operating as domestic U.S. firms, or in partnership with U.S. firms.

Information on the expenditures for microelectronic facilities by these entities is not available. Information is available, however, on the number of facilities established.

The following is a tabulation of new microelectronic manufacturing facilities established in the U.S. and funded by U.S. corporations that are at least partly owned by Japanese firms (SHC, 1988):

Nippon	-	4 facilities
Toshiba	-	3 facilities
Fujitsu	-	5 facilities
Mitsubishi	-	4 facilities
Sony	-	5 facilities
Hitachi Ltd.	-	3 facilities

CHAPTER 6:

INTERNATIONAL ACTIVITIES IN ADVANCED MACHINE TOOL INDUSTRIES

6.1 INTRODUCTION

Advanced metalworking machine tools which comprise machine tools *per se*, flexible manufacturing systems, and robots, represent an important manufacturing sector in a country's economy.

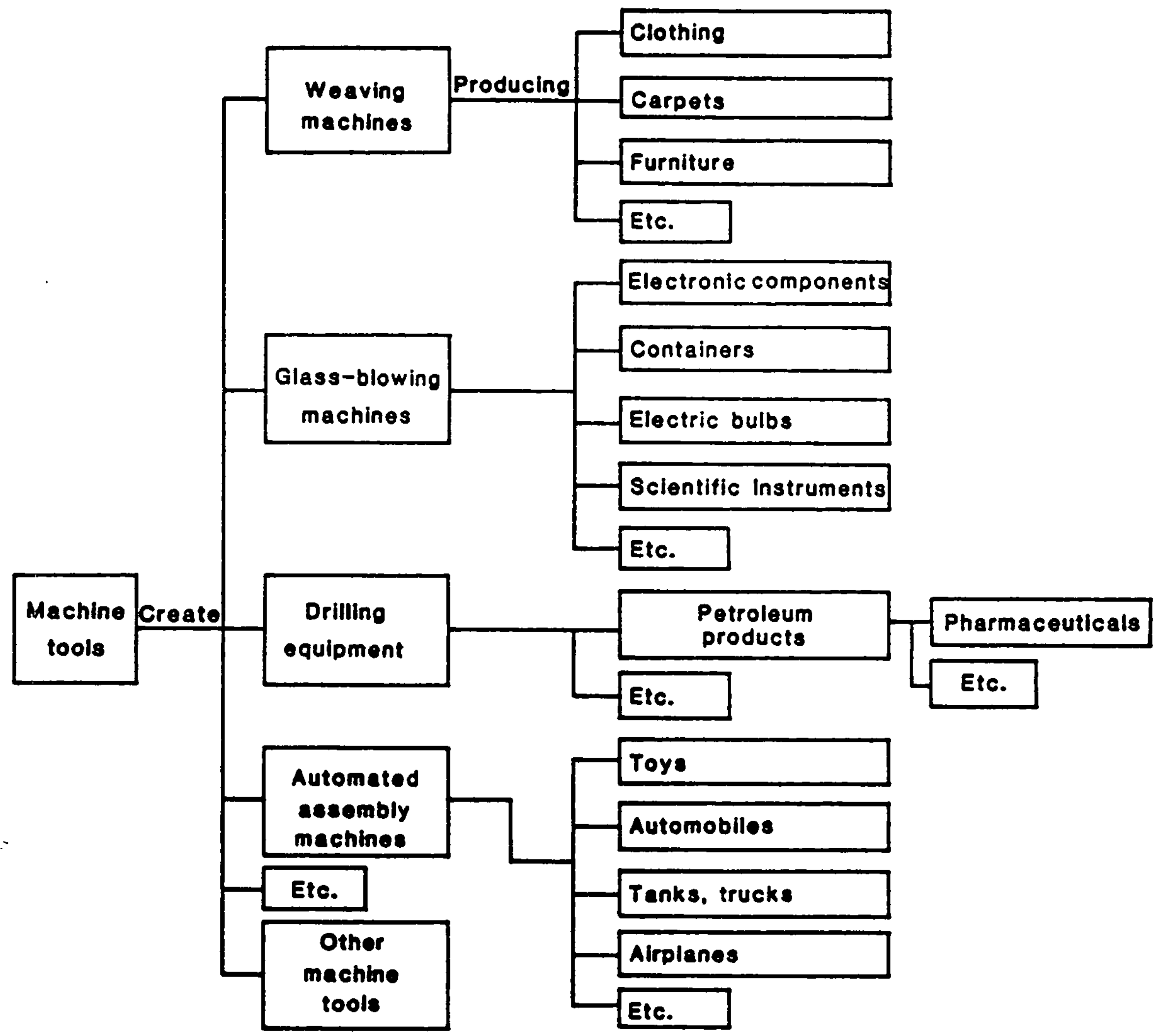
The scientific, research, development, and engineering activities in the area of metalworking machinery are of cardinal importance to any country's industrial achievement, economic performance and international competitiveness (Manufacturing Studies Board, 1988). Metalworking machinery is the basis for production in many other sectors of manufacturing, and equally important, metalworking machinery in itself is a significant commodity in international trade (Albus, *et al*., 1980).

Machine tools have long-linked economic impacts across and among most industry sectors. See Figure 6.1.

Machine tools are responsible, directly or indirectly, for most other manufactured products. They either produce the machinery which produce the products, or they produce the products directly.

Figure 6.1

Interindustry Dependence on Machine Tools



Source: NAMTB Handbook, 1985.

Machine tools are the only machines capable of producing other machines, including other machine tools. Machine tools are responsible for the increase in industrial productivity of a nation and are the standard by which a nation's industrial development and wealth are measured (NAS, 1983).

Metalworking machine tools are machines used for shaping or surface-working metals, whether by cutting away or otherwise removing the material or by changing its shape or form without removing any of it. Metalworking machine tools are officially classified as one of two types -- metal-removing or metal-cutting, and metal-forming.

Machine tools were initially developed in the mid-1880's principally in the U.K. with additional development in Germany, the U.S. and France (Rosenberg, 1963). Until the early 1940's, machine tools consisted of two basic components, the metal cutting blade which removes/shapes metal surfaces and the power source for the cutting blade.(1) The guidance of the cutting blade along the surface of the metal part was accomplished by mechanical operations, using patterns, jigs, clamps, etc.

The first major technological development this century was numerical control (NC) for metal processing machines, developed in 1952 at the Massachusetts Institute of Technology (MIT) (Charles Stark Draper Laboratory, 1983). NC involved feeding a successive stream of co-ordinates into a machine, usually via punched paper tape, which then guided the cutting tool. It provided faster and more perfect copies than the templates which had traditionally been used. MIT's experiments were of interest to the DOD and became the backbone of the U.S. DOD Manufacturing Technology (Man Tech). However, it was not until 1960 that NC technology began to be used commercially (Rendeiro, 1984; Birk and Kelly, 1980).

In the late 1960's the mechanical operations which guide the cutting blade were gradually replaced by electronic control systems. A series of advances in machine tools followed NC technology in rapid succession. Programmable contol (PC) machine tools were introduced in the late 1960's; direct numerical control (DNC) machine tools appeared in the early 1970's; computer numerical control (CNC) machine tools were used commercially in the mid-1970's; and various types of robots began to be used in the late 1970's (Blakeman, 1983).

The most advanced configuration of machine tools is referred to as computer integrated manufacturing (CIM). (The EEC member nations refer to CIM-type machine tools as advanced manufacturing technology -- AMT.) Horn states:

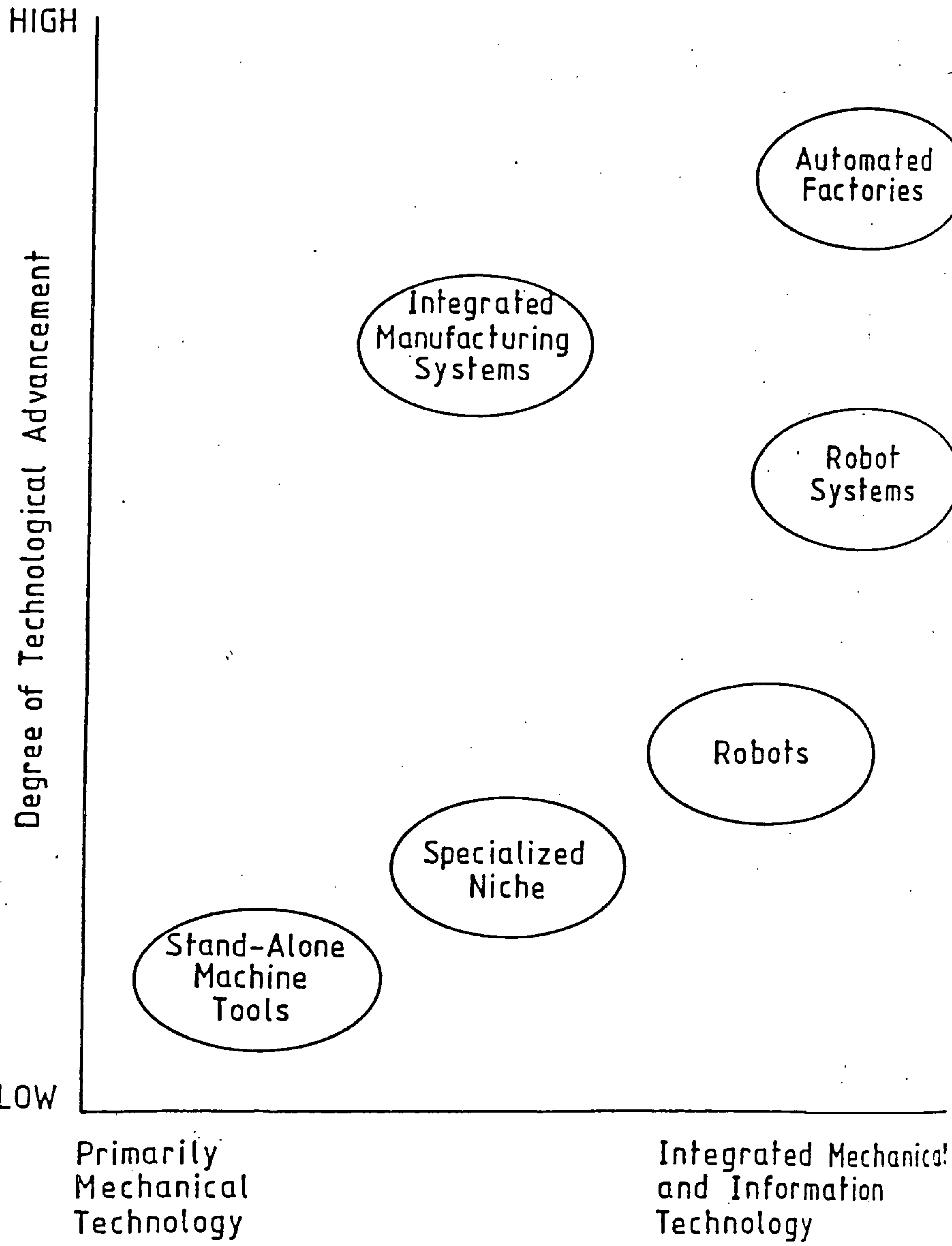
> The (metal working) machine tool industry has recently experienced a number of distinct changes. First, the links with microelectronic technology have been becoming increasingly close: the emergence of CNC machine tools is a prominent example. Second, the interface of

machine tool production with industrial robotics and other forms of computer aided manufacture, with computer aided design, and recently the advanced flexible manufacturing systems, has been growing. Third, new soures of supply, in particular Japanese firms, have disturbed traditional structures of international trade and production. Finally, the nature of the industry is changing. Having been formerly a vertically integrated industry, the machine tools industry is, through the link with microelectronics, increasingly becoming an assembly-type industry, importing strategic components, such as electronic controls. It is interesting to note that the suppliers of electronic controls have been reluctant to enter machine tool production proper, although they have moved into industrial robotics. The latter is at the most sophisticated end of the spectrum where microelectronics counts most. Potential users, particularly automobile firms, have pioneered many technical developments in this area (Horn, Kludt and Saunders, 1986).

At the present time (1988) there coexist several generations of machine tools. As shown in Figure 6.2, machine tool technologies located at the lower left side represent older technology vintages, whereas technologies located at the upper right side represent the most advanced machine tool development.[2] However, while there exists a secular tend in world machine tool sector towards more advanced technologies, the rate of diffusion of the most advanced technologies is relatively modest (Daly, et al., 1985; Junne, 1984). There are two principal reasons for this. First there is the high cost of advanced machine tools, and second is the availability of a large number of machine tool technologies of the older technology vintage (Cooper, 1984).

Figure 6.2

Machine Tool Technology
Gerations in Use, 1988



Source: George Sutton, Flexible Machining Systems, SRI International, Palo Alto, 1982.

Robotic systems and automated factories comprised of robotic systems represent the most advanced machine tools. Robotic systems are described as reprogrammable, multifunctional manipulators designed to move material, parts, tools, or perform a variety of tasks (RIA, 1980). The programming capability of the robotic systems permits the devices to operate independently of human operators and provides flexibility for adapting to various operations (OTA, 1984; NRC, 1983). The utilization of robotic systems in manufacturing has been modest in most industrialized nations except for the U.S. and Japan (Dennicott, 1982).

In Japan the application of robotic systems has received a favourable reception. Japanese manufactured robots are rapidly advancing in the world's markets as a result of the policies of the Japanese government, and because of the increasing use of microelectronic components in the manufacture of advanced machine tools. As stated by Horn, et al.:

> The machine tool industry is not a concentrated industry. In most countries it consists of a small number of big firms, most of which already played a distinguished role in the industry at the beginning of the century, and a large number of middle-size and small firms. The larger firms normally meet the demand of concentrated sectors such as automobiles, aerospace and armaments, while small firms are highly specialised in many different market segments with much smaller-scale demand. Looking across countries, it appears that the Japanese machine tool industry, a newcomer by international standards, is the most concentrated, but only in specific sectors of the market. Overall, the industry is less concentrated than at first sight appears. The reason seems to lie in the fact that in the supply of concentrated sectors a number of the

leading machine tools firms are affiliates of the conglomerates in automobiles, engineering and electronics (Horn, et al., 1986).

6.2 WORLD WIDE TRENDS IN MACHINE TOOLS

Some machine tool manufacturing occurs in twenty-five countries, however four countries dominate this industry -- the U.S., Japan, the U.S.S.R. and Germany (U.S. ITC, 1983).

The consumption and international trade in machine tools is determined by the vintage of the existing machine tool stock, economic conditions, and the relative magnitude of the machine tool industry in a country's economy. In 1988 the total worldwide production of machine tools was estimated at $38.4 billion, a significant increase over the 1967 estimate of $6.6 billion and over the 1980 estimate of $26.5 billion, the year with the highest production of machine tools on record. The trends in machine tool production during the last ten years, show an increase from 1977 to 1980; a decline from 1980 to 1983 and a very sharp increase from 1983 to 1988 (Table 6.1 and Figure 6.3).

TABLE 6.1

World Machine Tool Production, 1967 to 1988
(Millions of Dollars)

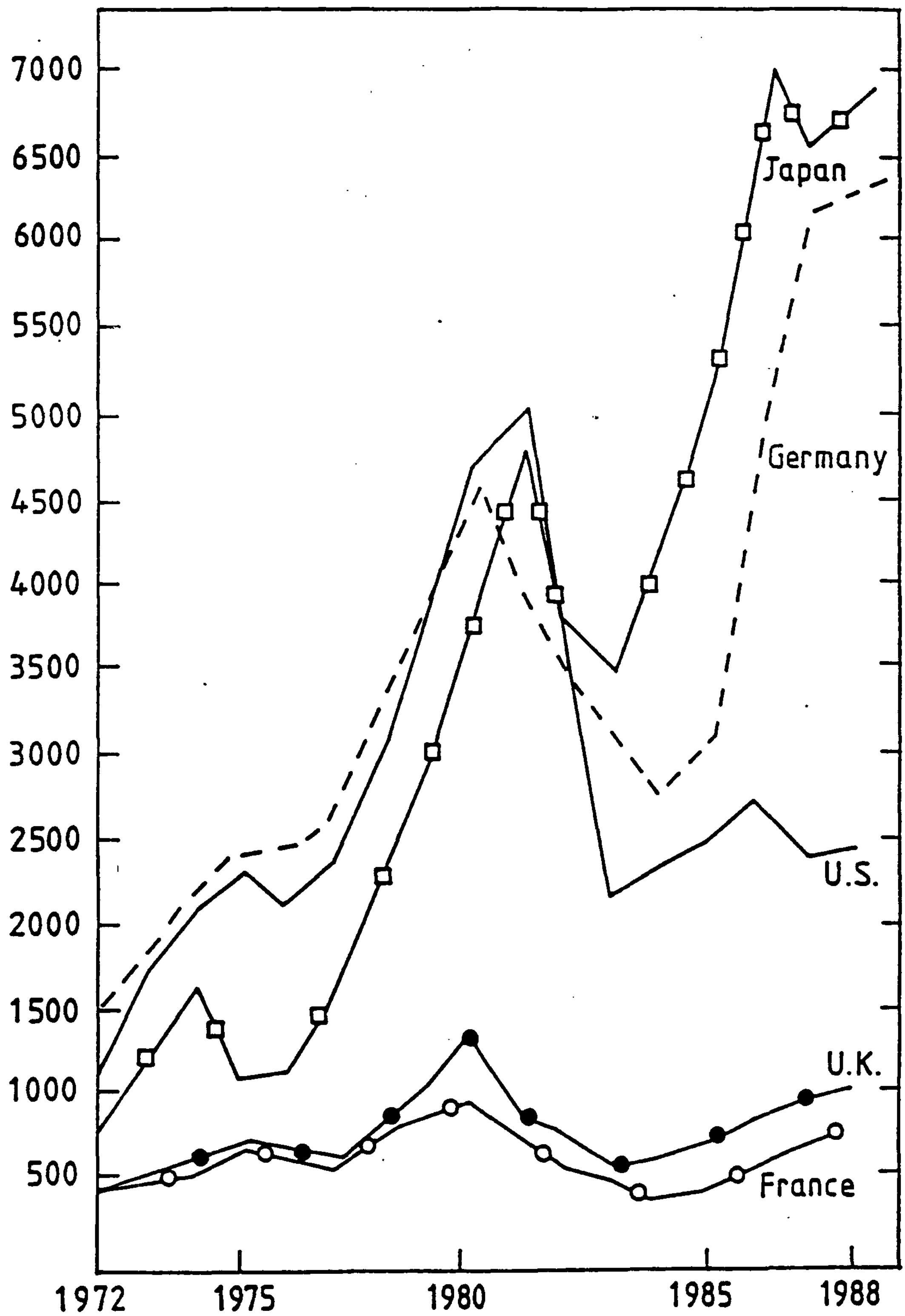
YEAR	TOTAL*	METAL CUTTING	METAL FORMING
1967	6,624.2	4,894.3	1,678.7
1970	8,268.2	6,069.2	2,142.0
1975	13,640.0	9,844.3	3,795.7
1980	26,501.3	20,268.4	6,232.8
1981	26,209.5	20,274.9	5,934.5
1982	22,071.3	17,171.4	4,957.0
1983	19,422.3	15,024.2	4,397.7
1984	20,805.9	15,900.8	4,905.1
1985	21,918.1	16,997.2	4,920.9
1986	28,890.6	22,105.4	6,785.3
1987	31,340.1	23,584.8	7,755.2
1988	38,400.0	27,600.0	10,800.0

*Metal cutting and metal forming may add to less than the total because a breakdown was not available for some countries.

Source: McGraw-Hill, Inc., American Machinist, June 1989. Uniform International Statistics on Machine Tools, and statistics reported by individual countries' machine tools associations.

Figure 6.3

Machine Tool Shipments from
Selected Countries, 1972-1988
(in millions of current dollars)



Source: NMTBA, Printouts, 1989.

During the period 1977-1988, Japan, the U.S. and Germany shared the three top positions as world producers of metalworking machine tools. Germany's machine tool production climbed from $2.64 billion in 1977 to $4.7 billion in 1980, before declining to $3.95 billion in 1981 and $3.5 billion in 1982, only to increase to $6.3 billion in 1988. U.S. production followed a similar trend; however, unlike that of Germany, U.S. production was sustained through 1982, and in that year reached $5.11 billion, up from $2.44 billion in 1977, before plummeting to $2.2 billion in 1982. In 1988 it was estimated to be $2.4 billion.

During the period 1977-1981, production by Japan increased greatly, from $1.6 billion, making it the world's fourth largest producer in 1977, to $4.8 billion in 1981, surpassing Germany and putting it in second place behind the U.S. as the leading producer of machine tools. Japan's 1982 production was valued at $3.9 billion, surpassed only by that of the U.S. In 1988 Japan's production of machine tools was reported to be $6.5 billion.

In 1977, the five machine-tool-producing countries analyzed here -- France, Germany, the U.K., the U.S. and Japan -- together accounted for 59.0 percent of total world production (Table 6.2). By 1982, these five countries had increased their share of world production to 59.3 percent, but by 1988 this share had declined to 43.3 percent, and the relative position among these countries had

TABLE 6.2

Metalworking Machine Tools: Percentage Distribution of World Production, by the Selected Countries, 1977 - 1988

COUNTRY	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Japan	10.6	12.3	12.6	14.3	18.2	17.1	18.1	22.4	23.6	24.1	20.4	16.7
United States	16.1	15.8	17.7	18.0	19.3	15.9	10.8	12.7	11.7	9.5	20.5	6.8
West Germany	17.4	17.8	17.5	17.6	15.0	15.4	16.4	14.5	16.5	13.5	13.8	13.5
United Kingdom	3.9	4.3	4.4	5.2	3.5	3.2	2.9	2.8	2.8	2.7	2.8	3.1
France	3.9	3.8	3.8	3.6	3.1	2.7	2.9	2.5	2.8	2.9	3.1	3.2
All Others	48.1	46.0	44.0	41.3	40.9	45.3	48.9	45.1	42.6	47.3	39.4	57.8
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100

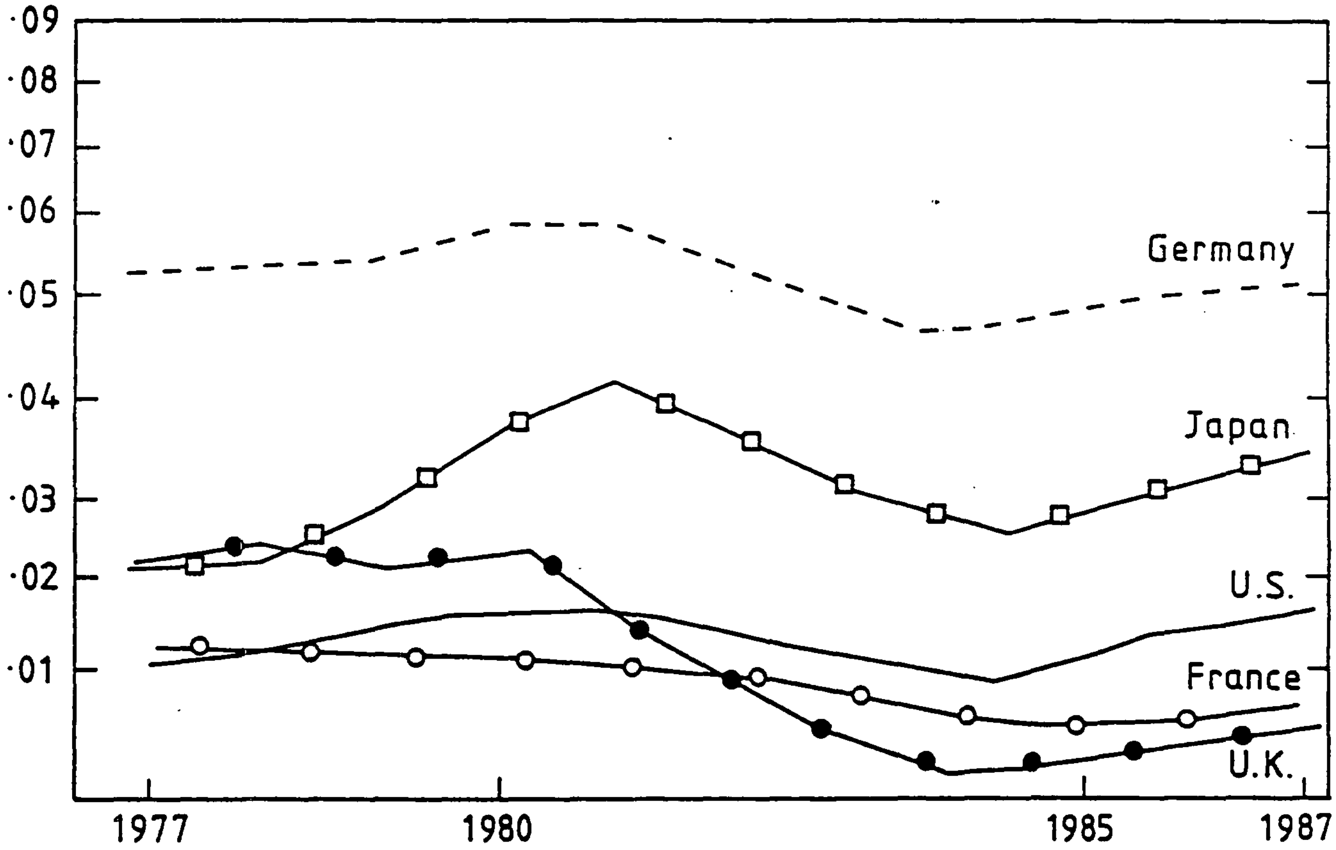
Source: American Machinist, June 1989.

changed considerably. Japan's share of the world market increased from 10.6 percent in 1977 to 16.7 percent in 1988. Conversely, Germany's world share fell from 17.4 percent to 13.5 percent over the same period. U.S. production of machine tools accounted for 16.1 percent of total world production in 1977 and reached 19.3 percent in 1981, before dropping to 6.8 percent in 1988. France and the U.K. accounted for 3.9 percent each of world machine tool production in 1977, but by 1988 the estimates were 3.1 percent for the U.K. and 3.2 percent for France.

One measure of the importance of machine tool production to national economies is the ratio of the value of machine tool production to the total GNP. This ratio varies significantly among the five countries (Figure 6.4). The value of machine tool production in Switzerland reached 0.094 percent of that country's total GNP during 1977-82, the highest such ratio recorded among major producing countries. Machine tool production in the U.K. accounted for 0.012 percent of GNP in 1982, and for 0.014 percent in 1988. Machine tool production in Germany fluctuated between 0.051 and 0.058 percent of GNP during 1977-82, representing the second highest among major machine tool producers. In 1988 this ratio was estimated at 0.053 percent. The ratio of Japan's machine tool production to its total GNP reached 0.042 percent in 1981, a rise of 0.023 percent from 1977. In 1988 this ratio for Japan was estimated at 0.039 percent. This represents the largest

Figure 6.4

Value of Machine Tool Production
as Percentage of GNP, Selected Countries,
1977 - 1987
(in percent)



Source: GNP data from International Monetary Fund, data tapes. Machine Tool production from American Machinist, June, 1989.

such growth in all major machine-tool-producing countries in the 1982 to 1988 period.

6.2.1 World Exports

Total world exports of machine tools increased at a relatively high rate from 1969 to 1980, then declined somewhat from 1981 to 1983, only to increase again from 1983 to 1988 (Figure 6.5).

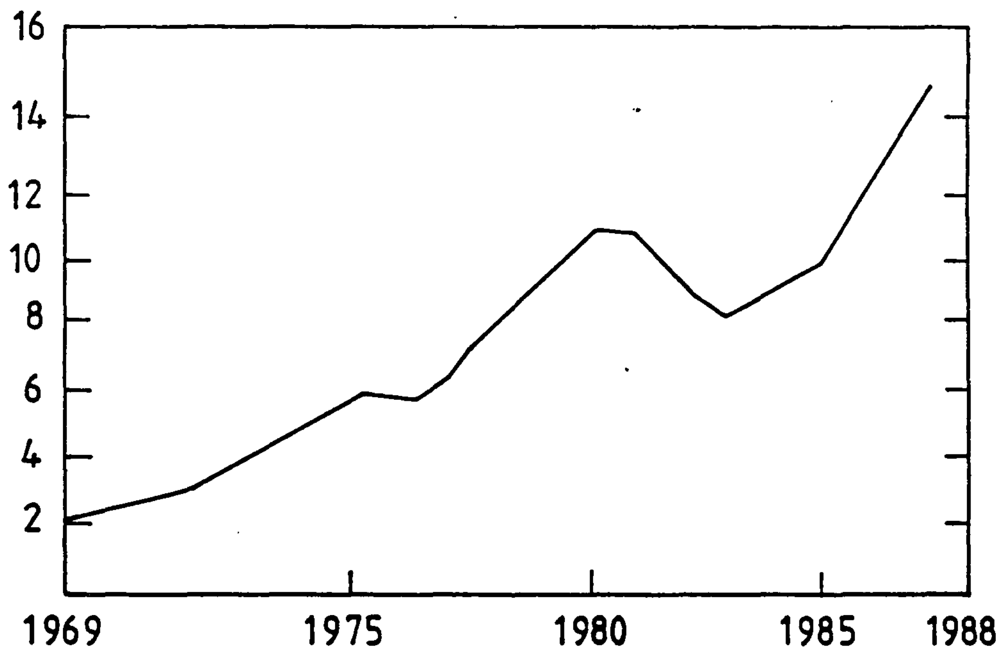
Germany and Japan consistently ranked as the major exporting countries between 1977 and 1988 (Figure 6.6). During the 1977 to 1988 period, German exports climbed from $1.8 billion in 1977, to $2.9 billion in 1980. Germany's exports then declined in each of the next 2 years, falling to $1.9 billion in 1983, only to increase to $3.6 billion in 1988. Japan's exports increased steadily during the period 1977-81, to $1.7 billion in 1981 from $616 million in 1977, a rise of 176 percent. Japan's exports fell to $1.3 billion in 1983, before increasing to $3.3 billion in 1988. U.S. exports increased from $470 million in 1977 to $876 million in 1981, only to decline to $620 million in 1982 and further to $610 million in 1988.

6.2.2 World Imports

Although annual imports of machine tools by most major importing countries fluctuated considerably, U.S. import growth

Figure 6.5

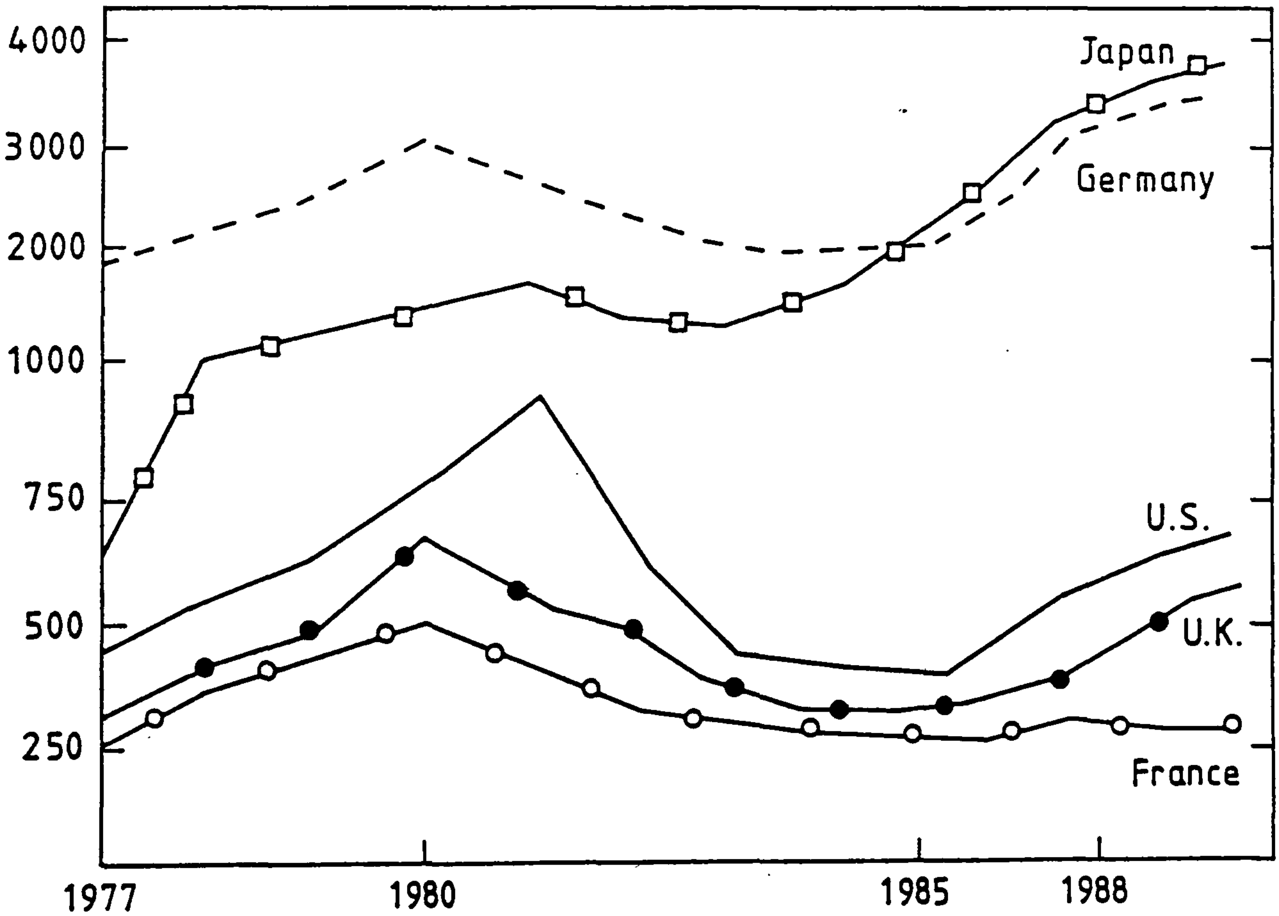
Total World Exports of Machine Tools, 1969 - 1988
(in billions of current dollars)



Source: American Machinist, July, 1971; September 1981; June 1989.

Figure 6.6

Exports of Machine Tools, Selected Countries, 1977 - 1988 (in millions of current dollars)



Source: American Machinist, July 1971; September 1981; June 1988.

during 1977-88 was the most striking (Table 6.3). U.S. imports grew from $401 million in 1977 to $1.44 billion in 1981, or by 259 percent. U.S. imports fell somewhat in 1982 to $1.3 billion, only to increase to $2.4 billion in 1988. Germany's imports of machine tools increased by 143 percent during 1977-80, from $320 million in 1977 to $802 million in 1980, before declining to $514 million in 1982, only to increase to $1.4 billion in 1988.

Machine tool imports by France and the U.K. increased significantly during the 1977 to 1988 period. In the case of Japan, machine tool imports have been historically of very low value. During the 1977 to 1988 period, machine tool imports increased from $88 million in 1977 to an estimated $260 million in 1988.

A comparison of information on imports, with data on production, clearly shows that the two major producers of machine tools, i.e. Germany and the U.S., are also the major importers of machine tools. Japan has had very modest imports of machine tools.

The reason for this pattern is that there exists a significant specialization among the major industrial nations in the manufacture of machine tools and therefore a nation with significant production of machine tools may also be an important importer of machine tools (NAS, 1983; SHC, 1988).

TABLE 6.3

Metalworking Machine Tools: Imports by Specified Countries, 1977-1988

(Millions of Dollars)

YEAR	UNITED STATES	GERMANY	FRANCE	UNITED KINGDOM	JAPAN
1977	400.9	320.4	286.2	238.3	87.8
1978	715.3	462.0	289.6	399.2	119.9
1979	1,043.8	620.9	371.4	600.4	164.3
1980	1,298.5	802.1	554.0	623.4	229.3
1981	1.437.0	616.4	566.6	432.0	215.8
1982	1,300.0	514.5	484.2	385.2	228.4
1983	1,321.0	562.3	463.2	362.0	167.7
1984	1,356.6	591.4	301.2	342.1	139.3
1985	1,725.0	467.0	350.0	342.1	222.5
1986	2,252.7	1,036.2	618.0	558.9	284.7
1987	2,025.0	1,270.4	715.4	539.6	281.0
1988	2,400.0	1,380.0	800.0	560.0	260.0

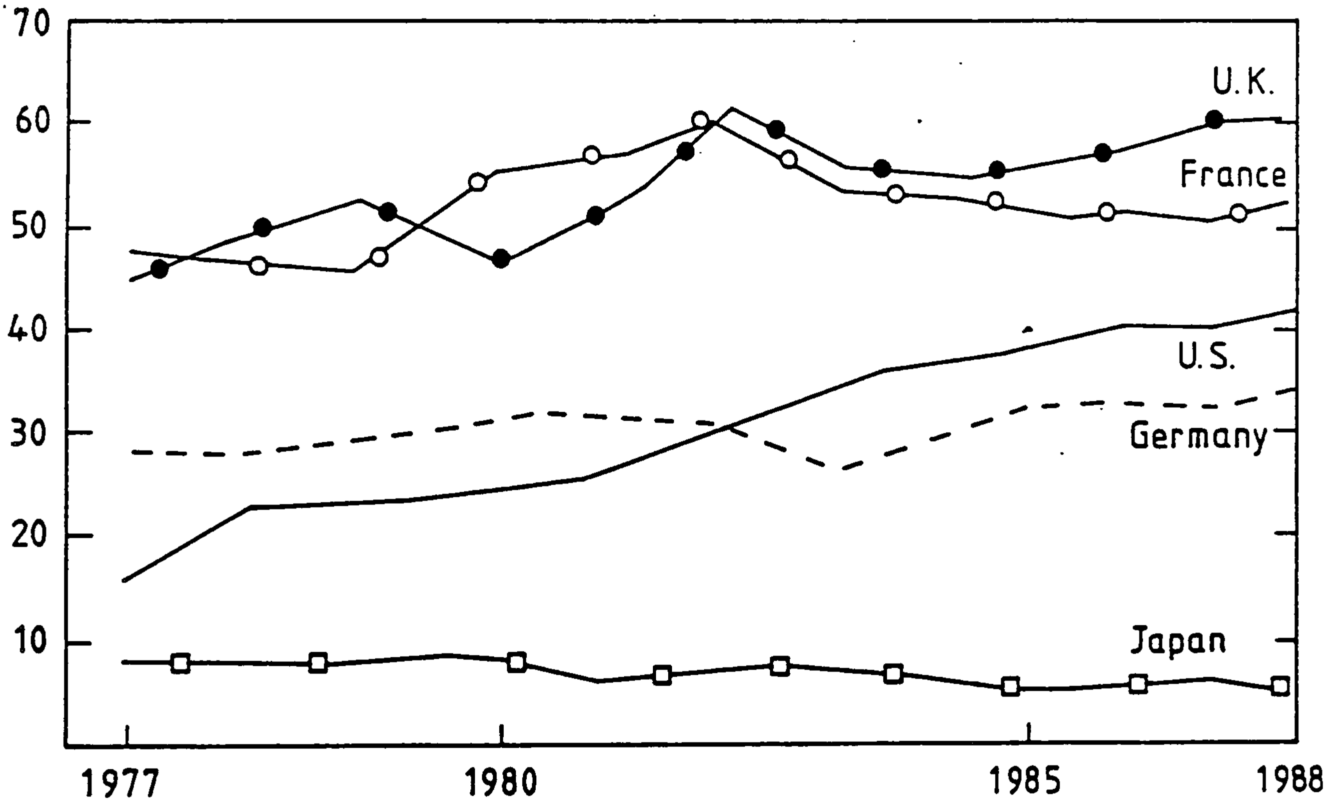
Source: American Machinist, June 1989.

For most years during 1977-1988, imports accounted for more than half of domestic machine tool consumption in France and the U.K. (Figure 6.7). For Germany and the U.S., imports represented about 20 to 30 percent of consumption, while for Japan this ratio was less than 10 percent. Among major machine-tool-consuming countries the U.S., the U.K. and France experienced the greatest growth of imports during 1977-1988. In the U.S., imports as a share of consumption increased to just under 40 percent in 1988 from almost 17 percent in 1977. Imports in both France and the U.K. were about 50 to 60 percent in 1988, representing increases of about 10 percent over 1977 imports. Germany's imports fluctuated between 28 and 32 percent during 1977-1988. Imports of machine tools accounted for only 8 percent of Japan's domestic consumption in 1988 -- the lowest such ratio of the major machine-tool-consuming countries. During the 1977-1988 period, Japan's ratio of imports to consumption peaked in 1980 at just over 9 percent.

6.2.3 World Consumption of Machine Tools

The very cyclical nature of the machine tool industry can be readily seen from information provided in Figure 6.8, which shows the consumption of machine tools by the five largest consuming nations, the U.S., Germany, France, Japan, and the U.K., for the 1967 to 1988 period.

Figure 6.7
Machine Tool Imports as a Share
of Domestic Consumption,
Selected Countries, 1977 - 1988
(in percent)



Source: American Machinist, September, 1981; June 1988.

The wide fluctuations in consumption levels place the machine tool manufacturing sector in all nations at a distinct disadvantage in planning for production, inventories, capital expenditures, etc. (NAS, 1983; NRC, 1983).

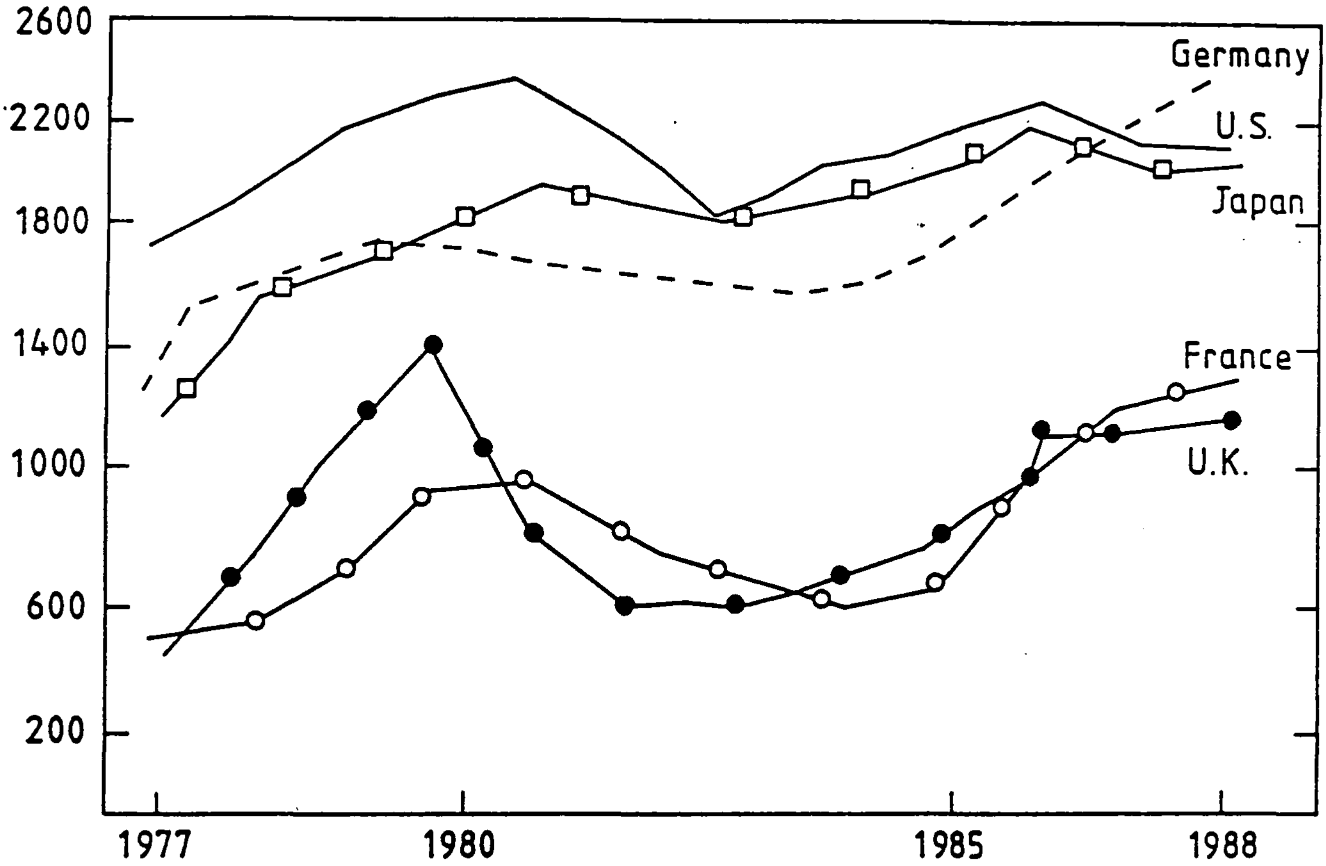
The estimated consumption of machine tools by the five countries increased dramatically from $6.3 billion in 1977, to $9.9 billion in 1988. The consumption trend lines for the 1977 to 1988 period are relatively stable, although (Japan excepted) a decline in machine tool consumption occurred between the years 1980 and 1985. One of the principal reasons for this decline was the merging of microelectronic and metal cutting technologies in machine tool design, combined with the reluctance by the industrial sectors to adopt this very advanced and innovative technology. Various government industrial policies helped to overcome this resistence to advanced machine tool technology (with varying degrees of effectiveness).

6.3 MACHINE TOOL INDUSTRY IN FRANCE

The machine tool industry sector in France is relatively modest, with 1988 production valued at $780 million (Table 6.4). There has been a very modest growth in French machine tool production during the last ten years with 1977 production valued at $620 million as compared to the average annual production during the 1986 to 1988 period of $717 million.

Figure 6.8

Consumption of Machine Tools,
Selected Countries, 1977 - 1988
(in millions of current dollars)



Source: NMTBA data tapes, 1988.

Imports of machine tools have doubled during the same period, but their value has remained small with 1980 imports estimated at $730 million (Table 6.5). Exports of machine tools from France over the period have averaged around the $300 million mark, except for 1980 and 1981 when France's exports of machine tools were valued at between $500 and $600 million.

Consumption of machine tools in France in 1977 was valued at $600 million, in 1988 this figure stood at $1,200 million (Table 6.6). The French machine tool association, Syndicat de la Machine Outil de l'Assemblage et de la Productique Anociee (SYMAP), reports limited future prospects for the French machine tool sector.

6.4 THE MACHINE TOOL INDUSTRY IN GERMANY

The German machine tool industry developed during the second half of the 19th century, and by 1900 this German sector dominated the world market for machine tools (Hutton, 1977). In the past sixty years, Germany has accounted for at least a third of world exports of machine tools. The industry recovered ground after World War II, and equalled machine tool production in the U.S. in 1960. In the 1970's German exports of machine tools were three times those of the U.S. and over four times those of the U.K.

TABLE 6.4

Production of Machine Tools, France, 1977 - 1988

(in millions of current dollars)

1977	620.5
1978	750.0
1979	877.2
1980	910.2
1981	760.8
1982	560.0
1983	561.3
1984	516.7
1985	468.0
1986	657.2
1987	715.4
1988	780.0

Source: American Machinist, June 1989.

TABLE 6.5

Imports and Exports of Machine Tools, France, 1977 - 1988

(in millions of current dollars)

YEAR	IMPORTS	EXPORTS
1977	281.0	382.2
1978	350.0	401.1
1979	374.1	458.3
1980	544.3	520.0
1981	580.0	620.6
1982	410.0	390.4
1983	351.3	295.2
1984	290.6	286.1
1985	350.0	228.3
1986	618.0	308.0
1987	715.4	282.9
1988	730.0	290.0

Source: American Machinist, June 1989.

TABLE 6.6

Consumption of Machine Tools in France, 1977 - 1988

(in millions of current dollars)

1977	680.2
1978	705.2
1979	790.2
1980	993.9
1981	999.8
1982	940.2
1983	617.5
1984	516.5
1985	589.7
1986	967.2
1987	1147.9
1988	1200.0

Source: American Machinist, June 1989.

In 1988, Germany's machine tool industry was well developed and extensive. The level of employment in the German machine tool industry is about twice that in the U.K., about fifty percent larger than in the U.S., and one-third as large as in Japan. The German machine tool manufacturing facilities are larger (in terms of employment and output) than those in the U.K., France and the U.S., but smaller than those in Japan (Carter, 1984; Hort, et al., 1986).

In 1988, Germany was the world's second largest machine tool producing nation, with shipments valued at approximately $6.3 billion (Table 6.7). It is the largest machine tool exporting country in the world, exporting 63 percent of its 1988 production. In 1988, machine tool imports amounted to approximately 29 percent of domestic consumption in Germany (Tables 6.8 and 6.9).

The importance of exports to the German machine tool industry can be readily seen from the information presented in Table 6.9. During the 1977 to 1988 period Germany exported 50 or more percent of its production. Imports of machine tools in Germany has remained stable over the same period (Figure 6.9).

The relatively large level of imports of machine tools into a nation which is one of the leading exporters of machine tools only underscores the significant international trade in this commodity.

TABLE 6.7

Production of Machine Tools, Germany, 1977 to 1988

(millions of current dollars)

1977	2,600.2
1978	3,288.9
1979	4,006.8
1980	4,707.6
1981	3,953.5
1982	3,504.9
1983	3,193.5
1984	2,803.7
1985	3,123.1
1986	5,185.4
1987	6,241.5
1988	6,300.0

Source: American Machinist, June 1989.

TABLE 6.8

Imports and Exports of Machine Tools, Germany, 1977 to 1988

(in millions of current dollars)

YEAR	IMPORTS	EXPORTS
1977	560.5	2431.1
1978	580.3	2400.2
1979	620.9	2508.6
1980	843.2	2926.3
1981	620.2	2430.0
1982	503.1	2101.1
1983	453.1	1950.4
1984	456.8	1967.7
1985	591.4	1899.8
1986	1036.2	2993.3
1987	1270.4	3314.0
1988	1400.0	3600.0

Source: American Machinist, June 1989.

TABLE 6.9

Proportion Machine Tool Imports to Exports Germany, 1977 - 1988

YEAR	PERCENT OF PRODUCTION EXPORTED	IMPORTS AS PERCENT OF EXPORTS
1977	70.2	9.5
1980	62.6	29.2
1981	65.6	26.0
1982	60.7	22.1
1983	58.6	23.1
1984	61.2	20.7
1985	57.8	19.8
1986	60.0	20.2
1987	52.8	17.3
1988	63.1	19.7

Sources: VDMA, "Statisches Handbuch fur den Maschinenbau" annually; "Die Lage des Maschinenbaues im Jahre" annually; foreign trade statistics from American Machinist, June 1989.

Japan has been the principal beneficiary of machine tool imports by Germany. This has taken place as a result of Japanese technological advances in machine tools, advances more pronounced than those of the leading machine tool exporters. Japanese machine tools have dominated German imports since the mid-1970's and in one year alone, (1980), imports of Japanese machine tools to Germany increased by 90 percent.

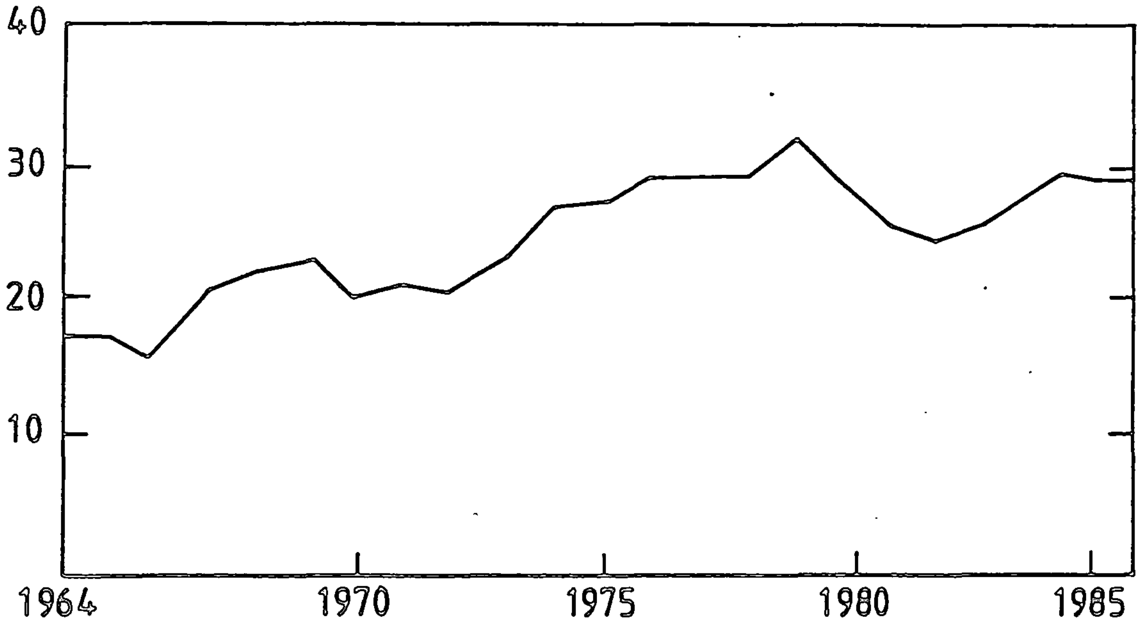
The consumption of machine tools in Germany has more than doubled during the 1977 to 1988 period. In 1977, German consumption was estimated at $2 billion, and by 1988 it had increased to $4.3 billion (Table 6.10).

In summary, the German machine tool industry, while remaining an important economic sector in Germany and a major force in world markets, is gradually losing ground to more advanced Japanese products on its native soil and in international trade. This conclusion is also shared by the U.S. National Academy of Sciences which reported on the German machine tool sector as follows:

> It is made up of a large number of small firms (only 15 out of 450 have more than 1,000 employees), with median employment slightly below 500. A great many firms are family businesses which have tended to specialise within relatively narrow market segments. This diversity has in the past given the industry great flexibility, but with the advent of the general purpose CNC machining centres, adjustment has proved more difficult because, as pointed out earlier in this chapter, it has turned upside down the traditional economics of the industry. There are now benefits to be gained from relatively long (300-400) runs of standard machining centres or CNC

Figure 6.9

German Machine Tool Imports as Percent of Domestic Consumption, 1964 - 1987 (in percent)



Source: American Machinist, May 1968; June 1976; July 1981; June 1989.

TABLE 6.10

Consumption of Machine Tools, Germany, 1977 - 1988

(in millions of current dollars)

1977	1982.5
1978	2003.0
1979	2119.1
1980	2609.8
1981	2430.0
1982	1982.1
1983	1696.2
1984	1510.9
1985	1814.8
1986	3228.2
1987	4197.8
1988	4300.0

Source: *American Machinist*, June 1989.

lathes, whereas the flexibility offered by these machine tools reduces the advantages of standard runs and large batch production in the engineering industry using these tools.

The concentration on the high-quality, customised product helps to explain the rapid penetration of the German market by Japanese NC machine tools when they first appeared in the mid-1970s. The Japanese share of the West German market increased from 5 per cent in 1977 to 13 per cent in 1981, but this included over 50 per cent of the machining centres bought in the country. At the same time, and perhaps more significantly, West Germany's share of machine tool exports slumped form 35 per cent to 24 per cent. This decline was largely attributable to West Germany's failure to match Japan's progress in NC machine tools. For example, in 1980, West Germany's sales of NC controlled lathes were only half those of Japan. But, while markets for NC machine tools were increasing rapidly, those for non-NC tools were stagnant or declining (NAS, 1983).

German industry's inability to match Japanese tool makers in the manufacture of numerically controlled machine tools contributed to the reative decline of the German machine tool sector. However, as discussed in Chapters 9 and 12, the Japanese tool makers were able to expand their exports to Germany and other nations at the expense of the Germans because of the deliberate policy by the Japanese government of supporting Japanese exports (Dennicoff, 1982).

6.5 MACHINE TOOL INDUSTRY IN THE U.K.

The machine tool industry in the U.K. began in the early 19th century, and by 1850 the U.K.'s machine tool industry dominated the world trade (Floyd, 1976). Available historical data suggest that over 60 percent of the world trade in machine tools in 1852 was held by U.K. firms. Germany and the U.S., however, were developing their own machine tool sectors, and by 1913 Germany dominated in international trade with 48 percent of the world exports in machine tools as compared to the U.K. at 12 percent and the U.S. at 33 percent (Daly and Jones, 1980).

There occured a minor revival in the share of U.K. exports in the period following World War II, but in secular terms, the U.K. machine tool industry has lost ground continuously (Kaplinsky, 1982). Between 1970 and 1977, U.K. machine tool production fell by a third. The production of the U.K. machine tool sector has increased in the last decade from $558 million in 1977 to $1.2 billion in 1988 (Table 6.11).

Imports and exports of machine tools during the 1977 to 1988 period remained relatively constant and almost equal in value (Table 6.12). However, the value of exports throughout the 1977 to 1988 period (about $300 to $400 million per annum) is quite small compared to the period price to 1977 when U.K. machine tool exports averaged $1 billion per annum. The decline of U.K. machine tool exports after 1983 in particular is significant. As stated by Horn:

> The disaster story of Europe has been the British machine tool industry. In the 1960s, the British were well ahead of their European competitors in both knowledge and use of NC tehnology. The virtual collapse

of this advantage, shown so dramatically by the fall in their share of EEC NC machine tool exports from 36 per cent to 5 per cent in the seven years 1976 to 1983, is sad testimony to the deep-rooted ills of the British economy. As in the case of computer aided design, it illustrates the British ability to grasp highly technical, highly sophisticated new technologies, but their abject failure to diffuse them more widely--a failure both of marketing (indeed even to appreciate the market opportunities that the technology offered, which both the Italians and the Japanese understood so well) and of technological competence, with the lack of skilled technicians seemingly the factor most severely inhibiting the diffusion of the technology in the United Kingdom. Government policies in the United Kingdom, aimed primarily at the diffusion of NC technology, have in fact brought the NC share of the total machine tool park in Britain well up to the level of its competitors, but it appears that lack of skilled technicians inhibits full advantage being taken of this position (Daly, Hitchens and Wagner, 1985). Moreover, these measures give no advantage to British-produced machine tools. The detailed trade statistics indicate that the British producers have now retreated to a highly sophisticated niche in the NC market: it now appears that they are hastening to fill the gaps in their product range by joint ventures with the Japanese; but such a lifeline does not necessarily help them cope with the next phase of this revolution, namely full-scale automation (Horn et al., 1986).

Consumption of machine tools in the U.K. in 1977 and in 1988 was essentially the same, about 1 billion. The information on machine tool consumption, shown in Table 6.13, indicates a relatively stable consumption rate during the 1977 to 1988 period of $1 billion per annum, except for the 1981 to 1985 period when consumption dropped by about $500 to $700 million. However, the consumption trends of machine tools in the U.K. is below that of of other industrial nations (Board of Trade, 1960; OTA, 1981).

TABLE 6.11

**Production of Machine Tools, United Kingdom
1977 to 1988**

(in millions of current dollars)

YEAR	UNITED KINGDOM
1977	587.9
1978	768.8
1979	1001.4
1980	1190.3
1981	932.9
1982	780.7
1983	573.4
1984	674.9
1985	722.9
1986	915.4
1987	940.3
1988	1190.0

Source: American Machinist, June 1989.

TABLE 6.12

Imports and Exports of Machine Tools, United Kingdom, 1977 - 1988

(in millions of current dollars)

YEAR	IMPORTS	EXPORTS
1977	581.0	483.3
1978	553.7	510.0
1979	600.4	473.1
1980	674.2	676.2
1981	481.0	411.0
1982	379.6	380.0
1983	294.3	318.6
1984	306.8	304.8
1985	342.1	335.6
1986	558.9	394.6
1987	539.6	459.5
1988	590.0	480.0

Source: American Machinist, June 1989.

The comparatively small size of the U.K. machine tool plants and an excess of marginal enterprises have contributed to the decline of this industry sector (Saunders, 1978). For example, in the 1960's the British government sponsored Industrial Reorganization Council (IRC) reported that "... fewer competing units are required in the machine tool industry" (Ministry of Technology, 1966). Attempts were made in the mid-1960's to the mid-1970's period to revitalize the machine tool sector, but with marginal results. As reported by Daly and Jones (1980):

> In the 1960s the largest machine tool concern in the country, Alfred Herbert, had absorbed with the IRC's encouragement a number of other large British machine tool makers (including the well-known machine tool department of BSA in 1966); Herbert had also come to an agreement in 1967 with a leading American concern, Ingersoll, to open a new plant in Britain under Herbert's control to make large special-purpose transfer machines which were needed by the motor industry. The employment of the Herbert group grew from some 6,000 at the end of the 1950s to a peak of 15,000 in the 1960s. At its peak this group accounted for close to a fifth of the British machine tool industry's output.
>
> The IRC took a direct interest in machine tools when it decided to provide financial support to the Herbert-Ingersoll venture in 1970. The sum invested at that first step was a modest L2.5 million. Smaller sums were also invested in two other machine tool companies. Within two years it became clear that the investment in Herbert-Ingersoll had been an unfortunate mistake, and this subsidiary went into receivership. The trading profits of the Herbert Group had in the meantime declined from year to year since their peak in 1967; the design of their products was too conservative for the modern world, and the group's management was not adequate for its widened responsibilities following the take-overs in which it had been encouraged to take part. By 1974 the group was on the verge of liquidation.

TABLE 6.13

Consumption of Machine Tools,
United Kingdom, 1977 - 1988

(in millions of current dollars)

1977	1006.6
1978	1030.4
1979	1128.7
1980	1190.3
1981	720.0
1982	620.6
1983	549.2
1984	587.0
1985	729.3
1986	1079.7
1987	1020.4
1988	1100.0

Source: American Machinist, June 1989.

Revitalization efforts were continued after the mid-1970's by the newly-formed National Enterprise Board with signficant infusions of capital in 1974 and 1975. However, the industry remained small and fragmented, and in order to correct this, attempts to aggregate British machine tool enterprises into larger units have continued (Board of Trade, 1960).

The latest rationalization of the U.K.'s machine tool industry was initiated in 1983, and has resulted in an increasing share of the domestic market for machine tools. For example, domestic machine tool builders such as Bridgeport, TI, Wadkin, and Beaver held 40 percent of home markets in 1987 as compared to 25 percent in 1982. Conversely, Japanese machine tool makers have increased their penetration of the U.K. home market and have established several manufacturing facilities in the U.K., including the very advanced Yamazaki plant in 1987 with the assistance of $8 million from the British government (SHC, 1988).

6.6 MACHINE TOOL INDUSTRY IN THE UNITED STATES

The machine tool industry in the U.S. began after 1850 and rapidly increased in size and importance in domestic as well as world markets (Fawcett, 1976). It became a major exporter in the first two decades of this century and dominated the world machine tool markets after World War II. More recently the machine tool sector in the U.S. has declined in terms of production, domestic and international sales and use of advanced technologies, in spite of the fact that most of the technological advances in machine tools were made in the U.S. (Carter, 1984). Daly, et al. (1985) summarize the machine tool industry in the United States as follows:

> The United States accounted for about a third of world exports of machine tools throughout the first half of the century; given the great absolute size of the American industrial sector, and the way its high labour costs encouraged the development of more sophisticated techniques, it is perhaps not surprising that American machine tools should have attained such a large share of international trade. But more recently, in the past twenty years, the United States gradually lost its great share in world exports following the rise of machine tool industries in other countries (such as Japan, Italy and, more recently, Korea and Taiwan). By 1977 the United States accounted for only a tenth of world exports of machine tools. Its industry has suffered a crisis in some ways similar to that of Britain (the real output of US machine tools fell by about a fifth between 1970 and 1977); but its vast home market continues to provide scope for economies of scale in those advanced machine tools, with rapid production speeds, in which it specialises.

Production of machine tools in the U.S. over the 1977 to 1988 period increased from $2.4 billion in 1977 to $2.6 billion in 1988 (Table 6.14). The year 1984 was a watershed for the U.S. machine tool industry as U.S. domestic production fell from about $5 billion in 1981 to $3 billion in 1982, only to decline to $2 billion in 1983, and the U.S.'s share of world production declined by some 11 percent. Production increases have remained very modest since 1983.

The import and export data on machine tools for the U.S. for the 1977 to 1988 period are shown in Table 6.15. A secular trend of the U.S. balance of trade in machine tools is presented in Figure 6.10 for the 1960 to 1988 period and shows the dramatic decline in the U.S. balance of trade in machine tools.

The principal beneficiary of the increasing imports of machine tools by the U.S. since 1976 has been Japan, which has replaced Germany as the principal exporter of machine tools to the U.S. (Figure 6.11). The reason for Japan's success in the U.S. market has been the technological advances incorporated in Japanese machine tools, as well as the Japanese government's support for machine tool exports.

Consumption of machine tools in the U.S. for the 1977 to 1988 period is shown in Table 6.16 and as the data indicate, the consumption of machine tools during the last decade has remained relatively stable except for the years 1983 and 1984 when consumption declined significantly due to worldwide recession.

TABLE 6.14

Production of Machine Tools, United States, 1977 - 1988

(in millions of current dollars)

1977	2400.2
1978	3000.0
1979	4059.1
1980	4820.0
1981	4920.2
1982	3001.6
1983	2106.4
1984	2423.2
1985	2575.0
1986	2747.9
1987	2435.0
1988	2600.0

Source: American Machinist, June 1989.

TABLE 6.15

Imports and Exports of Machine Tools, United States, 1977 - 1988

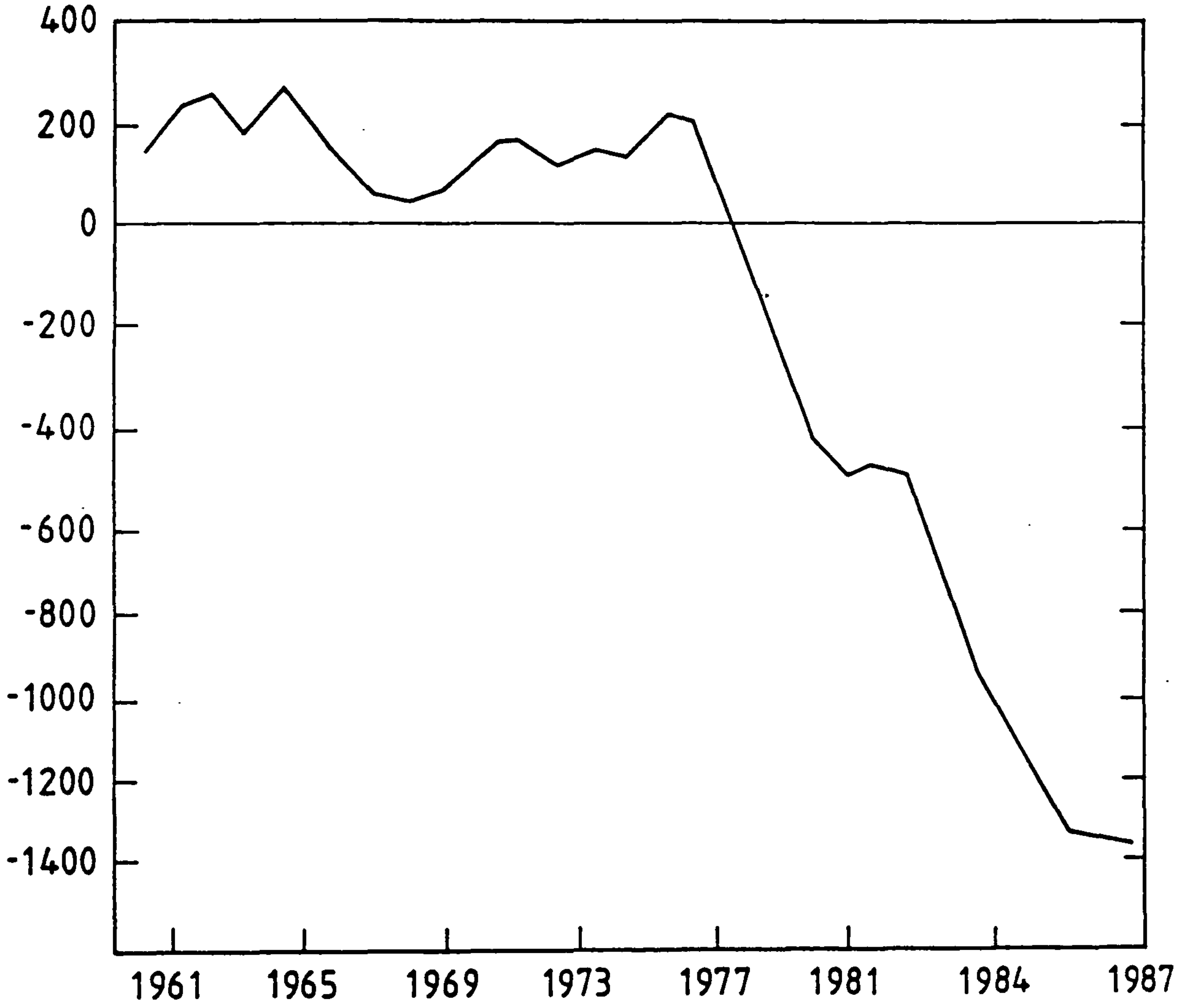
(in millions of current dollars)

YEAR	IMPORTS	EXPORTS
1977	671.0	680.8
1978	1120.2	630.0
1979	1043.8	648.8
1980	1303.0	748.0
1981	1201.0	840.4
1982	1107.0	620.0
1983	946.5	406.0
1984	1400.0	400.0
1985	1725.0	445.0
1986	2252.7	590.3
1987	2025.0	640.0
1988	2200.0	700.0

Source: American Machinist, June 1989.

Figure 6.10

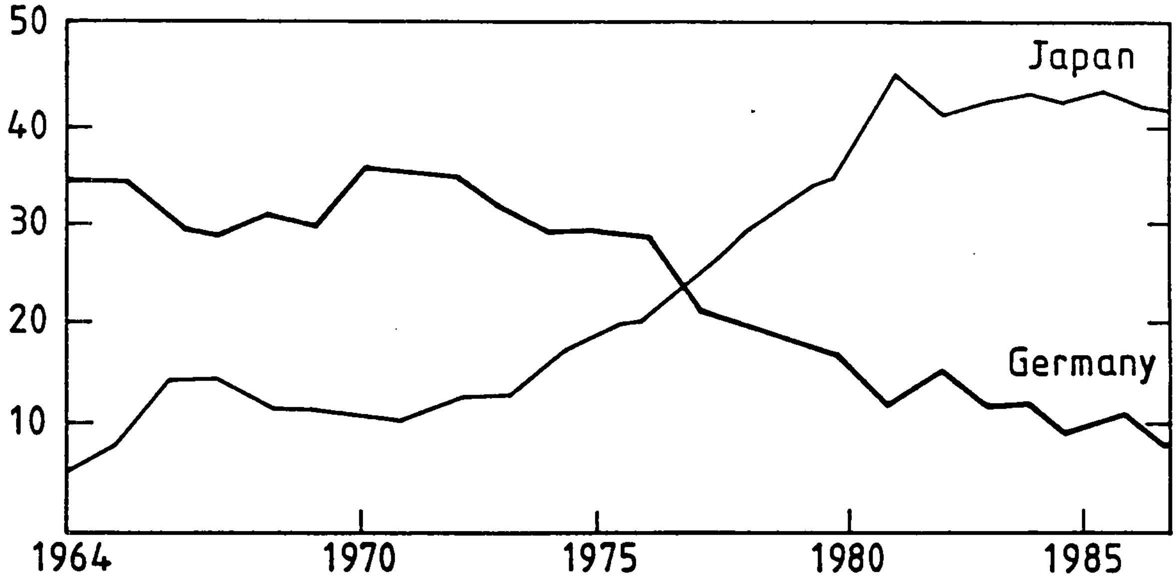
Trade Balance in Machine Tools, United States
1961 - 1987
(in millions of current dollars)



Source: NMTBA, Economic Handbook of Machine Tool Industry, 1987.

Figure 6.11

Machine Tool Imports from Germany and
Japan as Percent of Total U.S. Machine Tool Imports,
1964 - 1987
(in percent)



Source: American Machinist, June 1989.

TABLE 6.16

Consumption of Machine Tools, United States, 1977 - 1988

(in millions of current dollars)

1977	4505.5
1978	4603.3
1979	4454.1
1980	5375.0
1981	4302.0
1982	3600.1
1983	2646.9
1984	2861.1
1985	3393.5
1986	4410.3
1987	3820.0
1988	4200.0

Source: American Machinist, June 1989.

6.7 MACHINE TOOL INDUSTRY IN JAPAN

The machine tool industry in Japan shows extraordinary growth during the 1977 to 1988 period. Production of machine tools in Japan increased from $1.7 billion in 1977 to $6.7 billion in 1988 (Table 6.17). Exports increased from about $900 million in 1977 to $3.2 billion in 1988 (Table 6.18).

The growth of the Japanese machine tool industry is indeed extraordinary. In 1985, for example, Japan's production of machine tools was twice that of the U.S., and Japan represented almost 20 percent of total world production of machine tools. Between 1984 and 1985, Japan's exports of machine tools increased by 20 percent while consumption shows an equally strong growth trend, as shown in Table 6.19.

There are two principal reasons for the growth of the machine tool industry in Japan. The first of these is the technological advances made by the Japanese in machine tool design, principally in the merger of microelectronic and metal cutting technologies (Dennicoff, 1982). The second is the various Japanese policies enacted to foster the Japanese machine tool industry.

Japanese government policies to foster the machine tool industry in Japan are not a recent phenomenon. The initial Japanese government policy directed explicitly towards the machine tool sector was enacted on March 30, 1938 as the Machine Tool Industry Law, and policies to encourage the growth of the Japanese machine tool sector have continued to the present time as discussed in Chapter 12.

6.8 SUMMARY

The rapid growth of the Japanese machine tool industry in the world market represents the principal development in this important industry sector during the last two decades. This change is especially important because Japanese achievements were accomplished at the expense of the German and the U.S. machine tool makers, which together represented the leading suppliers of machine tools in the world since the late 19th century. Germany, in particular, was affected by the Japanese emergence as the leader in machine tool technology and production because their machine tools, prior to Japanese success, had world-wide acceptance and markets.

The Japanese advance in machine tools to the status of world leader is the result of extensive policies by the Japanese government. There are two principal components of these policies. The first of these consists of policies which represent a series of government laws, regulations, directives, and so forth, that encourage the development of so called "target industries" in

TABLE 6.17

Production of Machine Tools, Japan, 1977 - 1988

(in millions of current dollars)

1977	1680.0
1978	2315.0
1979	2892.7
1980	3817.5
1981	3603.0
1982	3619.2
1983	3542.2
1984	4473.4
1985	5269.7
1986	6872.2
1987	6413.7
1988	6700.0

Source: American Machinist, June 1989.

TABLE 6.18

Imports and Exports of Machine Tools, Japan, 1977 - 1988

(in millions of current dollars)

YEAR	IMPORTS	EXPORTS
1977	160.0	880.3
1978	159.5	910.0
1979	164.3	1236.5
1980	225.1	1456.4
1981	230.0	1320.4
1982	200.7	1300.7
1983	171.3	1263.6
1984	160.6	1691.7
1985	222.5	2098.9
1986	284.7	3063.5
1987	281.0	2933.3
1988	300.0	3200.0

Source: American Machinist, June 1989.

TABLE 6.19

Consumption of Machine Tools, Japan, 1977 - 1988

(in millions of current dollars)

1977	1790.0
1978	1832.0
1979	1820.5
1980	2586.2
1981	2381.0
1982	2390.0
1983	2448.8
1984	2861.1
1985	3393.3
1986	4897.4
1987	5303.2
1988	5700.0

Source: American Machinist, June 1989.

Japan (i.e. industries selected for preferential treatment by the Japanese government). This component consists principally of financial assistance by the government to Japanese machine tool manufacture in research and development, capital expenditures, and export sales.

The second component is somewhat unique. It consisted of the government's encouragement of, or even instruction to Japanese machine tool makers to combine the old "iron" technology (i.e. metal cutting) with the new microelectronic control instrument technology. The fact that the Japanese government has significant influence over its industry sectors was of considerable importance in the successful execution of these policies. In the U.S., Germany, and other countries, the merger of these two technologies in the manufacture of machine tools was delayed by the fragmentation of the machine tool sectors in these countries, and the absence of a central industry policy.

This delay by other countries in adopting advanced technologies in machine tools provided Japan with the opportunity to penetrate foreign markets successfully with their advanced machine tool products. These neotechnological advances achieved by Japan created a formidable obstacle to other nations attempting to recover their world market shares in machine tools (Maskers, 1987).

FOOTNOTES TO CHAPTER 6

1. The combination of the cutting blade and power source is referred to as the "iron" technology of machine tools, as opposed to advanced technology that includes micro-electronic controls.

2. Note that at any one time and place, several generations of machine tools may be used.

Chapter 7:

INTERNATIONAL ACTIVITIES IN ADVANCED MATERIALS INDUSTRIES

7.1 INTRODUCTION

The third scientific activity area for which comparative analyses of government science policies are undertaken is that of advanced materials. In several important respects the scientific and technology activities in advanced materials differ markedly from scientific activities focused on microelectronics, machine tools and other advanced technology products. The scientific field of advanced materials is exceptionally complex in that a very large number of advanced materials may be included under this rubric.

Within this study, advanced materials are limited to three specific types:

1. advanced ceramics;
2. advanced polymers; and
3. composites.

Another salient characteristic which differentiates this field of science from others is that the scientific and technological activities associated with advanced materials are in the early stages of the research and development phase.

Limited use is made of advanced materials for commercial applications as of 1988. Many current applications are those where the costs of such applications are only marginal considerations. Defence-related applications therefore dominate "commercial" uses of advanced materials. Internal and external trade in advanced materials is limited in most nations. Because the commercial applications of advanced materials are limited, there are no standard measures of economic performance for this sector, such as value of output or shipments.

There exist, as of 1988, very significant differences in government or private sector commitment to foster the science and technology activities related to advanced materials. The governments and private sectors of the U.S. and Japan have been supporting scientific activities related to advanced materials with significant commitments of funds, research programmes and subsidized production. In the U.K., Germany and France, government and private sector activities relating to advanced materials have been much more limited (NRC, 1987).

In many other respects, the field of advanced materials exhibits characteristics of other advanced technology areas. Advanced materials represent potential "building blocks" for a large number of industrial products and processes in a large number of industries. The future importance of advanced materials and the rate in increase of advanced material applications can be readily seen from the projections of advanced material production. These projections place the value of total non-communist world advanced material output at almost $160 billion in the year 2000 (Richerson, 1985).

These exceptional market projections for advanced materials are based on the equally exceptional physical and chemical properties of these materials which in turn create market demand. A few examples should indicate the exceptional properties of these materials.

In the case of engineering materials used in elevated operating temperatures, the materials currently used (titanium) have limits of $1000^{o}F$ to $1500^{o}F$. A class of advanced materials, have operating limits of $5000^{o}F$. The load carrying capacity of these composites will increase to 5000 psi as compared to the current limit of 400-500 psi (NRC, 1984). In the case of advanced ceramics, most advanced roller bearings manufactured from metal alloys operate at maximum temperatures of $120^{o}C$. The use of advanced ceramics, based on zirconium boride, will allow operations in temperatures exceeding $800^{o}C$.

There is no commonly agreed definition of "advanced materials," however as a working definition, advanced materials may be described as structures of physical matter which have been developed to meet specific predetermined needs. Clark, Kennedy and Bowen (1983) describe the advent of advanced materials as follows:

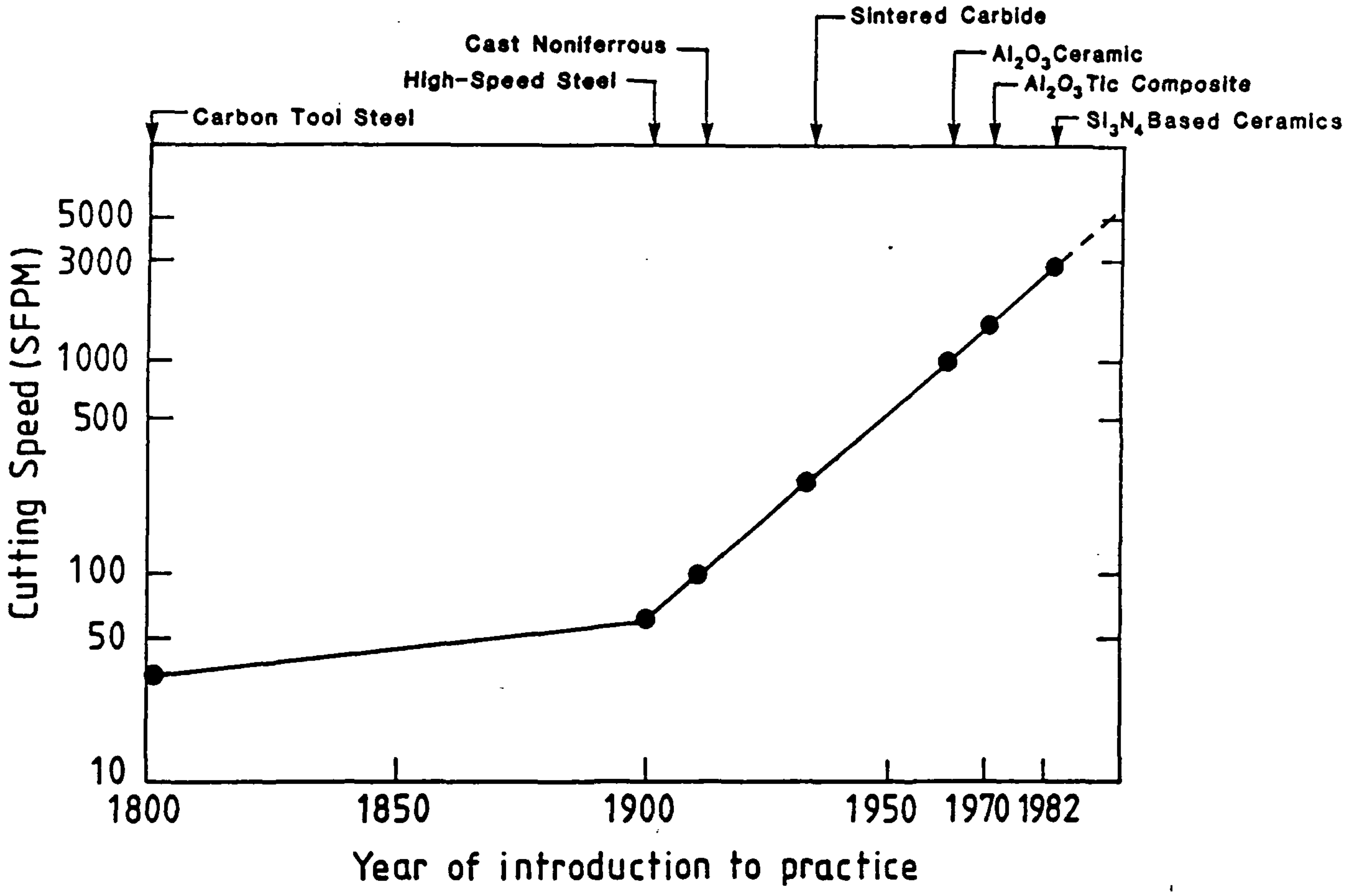
> "A fundamental reversal in the relationship between human beings and materials in taking place. Its economic consequences are likely to be profound. Historically humans have adapted such natural materials as stone, wood, clay, vegetable fiber and animal tissue to economic uses. The smelting of metals and the production of glass represented a refinement in this relationship. Yet it is only recently that advances in the theoretical understanding of the structure of physical and biological matter, in experimental techniques and in processing technology have made it possible to start with a need and then develop a material to meet it, atom by atom."

7.2 ECONOMIC IMPORTANCE OF ADVANCED MATERIALS

It is the potential economic benefits of advanced materials which stimulate scientific and technological activities as well as government policies to foster their further development. Explicit estimates of the economic benefits which may be derived from the application of advanced materials are very few. An excellent estimate of such benefits, however, is available in the case of the replacement of existing machine tool cutting materials with advanced ceramics (Johnson, et al. 1983). Figure 7.1 presents the cutting speeds of various machine tool materials with the year of introduction of the material during the 1860 to 1982 period. The feasibility of significantly increasing the cutting speeds by use of advanced materials, i.e., ceramics based on zirconium, is obvious from the information presented.

Figure 7.1

Average Cutting Speeds of Various
Machine Tool Materials
1800 - 1982



Source: U.S. Congress, The Machine Tool Industry and the Defense Industrial Base, Hearing before the Joint Economic Committee, Washington, D.C.: GPO, 1983.

The use of advanced ceramics in machine tools allows for much higher operating speeds which in turn reduces operating time and therefore machine cost. The economic benefits to be derived from the use of advanced ceramics in machine tools are very large.

It has been reported that the total annual machining costs in the U.S. are approximately $115 billion (U.S. Congress, 1976). The use of advanced ceramics in machine tools is estimated to reduce by about 40 percent the total time elapsed in machining operations (Bennett, 1986). Assuming that 60 percent of machining costs are attributed to labour hours, i.e., elapsed time of machining, the annual savings in machining costs using advanced ceramics are equal to about $28 billion.

The possibility of substituting certain advanced materials for critical (i.e., short supply) minerals may result in very large economic benefits.

As stated by Bennett (1986):

"Advanced materials offer comparable leverage in the area of such strategic minerals as chromium, managanese, cobalt and the platinum-group metals, which must now be imported. Materials scientists and engineers are now developing new metallic alloys and processing methods for them, as well as ceramics, polymers and composites that require little or no reliance on imported materials and often yield more efficient or cost-effective products. Advanced ceramics are particularly significant in this context. To be sure, the production of structural ceramics involves sophisticated chemical processing methods, and their cost and reliability are uncertain. Yet the solution of such problems would considerably

> reduce dependence on cobalt and tungsten in cutting and wear-resistant applications and on chromium, cobalt, manganese and platinum-group metals in automative components."

The substitution of advanced materials for metals such as cobalt would also reduce dependency on nations (*i.e.*, Zaire) that are politically unstable and therefore supply of the required raw materials (ores) cannot be assured.

Another economic advantage of advanced materials is the significantly reduced costs of manufacturing advanced materials as compared to the conventional manufacturing processes.

In this respect:

> "Often the competition is less between materials than it is between processes. Most automotive connecting rods, which link pistons to the crankshaft, are forged. In order to reduce cost in the final forming process, certain sections are significantly more massive than they need to be. There is, however, a penalty: considerable material is lost during forging and machining. A relatively new process avoids the difficulty. Called powder-metallurgy forging, it begins with a powdered metal. The powder is loaded into a preshaped form or cast and typically subjected to extremely high temperature and pressure. Because the cast shape is close to that of the finished product, wastage of material is minimized; the process also reduces the need for labor" (NRC, 1987).

7.3 FUTURE PROSPECTS FOR ADVANCED MATERIALS

Future uses of advanced materials are forecasted to be extensive and the growth of advanced material applications in industry, very rapid. Table 7.1 presents a comprehensive and authoritative forecast for advanced material use for the 1985 to year 2000 period. The information in Table 7.1 shows that the total worldwide use of advanced materials is expected to increase from about $19 billion in 1988 to $46 billion in 1990, to $88 billion in 1995. In the year 2000 the use of advanced materials is projected to be almost $160 billion.

7.4 ADVANCED CERAMICS: CHARACTERISTICS, USES AND ASSOCIATED SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES

Advanced ceramics are defined as solid materials that are neither metals nor polymers and have unique structures at atomic level. The most important characteristic of the unique structure of ceramic is the strong bonds that hold constituent atoms of the ceramic matter in place. At the atomic level, ionic and covalent types of bonding are encountered. As described by Bennet:

> A ceramic's characteristic properties derive from its structure, both at an atomic level and at scales ranging from micrometers (millionths of a meter) to millimeters. At the atomic level two types of bonding are encountered in ceramics: ionic and covalent. In ionic bonding electrons are transferred from one atom to a neighboring atom. The atom giving up the electrons thereby becomes positively charged and the atom accepting the electrons becomes negatively charged. The opposite ionic charges thus created bind the atoms of the material together.

Table 7.1

Trends in Use of Selected Advanced Materials, Worldwide, 1985 with Projects for 1990, 1995 and 2000 (in millions of 1987 dollars)

Type of Advanced Material Advanced Ceramics	1985	1990	1995	2000
1. Electromagnetic	8,586	16,898	26,265	37,669
1) IC substrates, packages, etc.	461	1,186	2,400	4,680
2) Thermistors, varistors, etc.	743	1,627	1,960	2,275
3) Magnetic substances	1,831	4,339	7,100	10,000
4) Condensers, piezo-electric elements	5,324	9,233	14,200	20,000
5) Spark plugs	237	513	605	714
2. Mechanical	580	1,020	1,645	2,082
1) Tools, high-hardness members	453	704	949	1,196
2) High wear-resist members	91	230	560	700
3) Others	36	86	136	186
3. Thermal	468	2,771	6,235	9,019
1) Heat-treatment jigs for semiconductors	161	796	1,820	3,800
2) High-temperature anti-corrosive members	191	1,755	4,143	4,887
3) Others				
4. Chemical & Medical	437	1,912	2,920	3,959
1) Sensors	318	703	840	975
2) Catalysts, carriers	119	209	330	484
3) Teeth, bones, joints, etc.	0	1,000	1,750	2,500
5. Optical	229	1,672	4,692	6,342
1) Optical fibres	197	1,620	4,620	6,250
2) Others	32	52	72	92
6. Others	175	990	1,489	2,190
1) Nuclear Energy	0	590	864	1,340
2) Others	175	400	625	850
Total	10,415	25,263	43,246	61,261

Table 7.1 (continued)

Advanced Ceramics	1985	1990	1995	2000
2. Advanced Polymers	6,810	12,690	21,048	33,590
1) General use engineering performance	3,960	6,500	9,828	14,280
2) High performance engineering plastics	1,170	2,080	3,640	4,980
3) Photo-resist materials	600	1,000	1,600	2,560
4) Photochromic polymers	-	100	450	1,670
5) Electronconductive polymers	120	610	1,530	3,500
6) Water-absorbent polymers	50	100	200	400
7) Ion-exchange resins	220	400	700	1,200
8) High-function separation membranes	750	1,900	3,100	5,000
3. Advanced Composites	645	2,346	7,110	21,020
1) Carbon fibre reinforced materials (base materials: P, M)	222	786	2,310	6,720
2) Aramid fibre reinforced materials (base material: P, M)	333	1,260	4,100	12,600
3) Ceramic fibre reinforced materials (base material: M)	-	100	300	900
4) Glass fibre reinforced concrete	90	200	400	800
4. Advanced metals	750	5,520	16,770	44,000
1) Solar cells	750	3,000	9,000	22,500
2) Amorphous metals	-	1,500	4,600	12,000
3) Metallic alloys for hydrogen storage	-	300	1,000	3,000
4) Shape memory alloys	-	100	300	900
5) Superconductive alloys	-	500	1,500	4,500
6) Thermoelectric alloys	-	90	270	800
7) High-performance permanent magnets	-	30	100	300
Total	8,205	20,556	44,928	98,610
Grand Total	18,620	45,819	88,174	159,871

Source: Richerson, 1985.

In covalent bonding electrons are shared more or less equally between neighboring atoms. Although the electrostatic force of attraction between adjacent atoms is less than it is in ionic bonding, covalent bonds tend to be highly directional, meaning that they resist the motion of atoms past one another. The hardest material known, diamond, is composed of covalently bonded carbon atoms.

Whether the bonds are mostly ionic or mostly covalent, they can arrange atoms into groups, called unit cells, that may be repeated periodically throughout the material. Such an ordered array of unit cells constitutes a crystal. If no periodicity beyond the local unit cell is evident, the material is noncrystalline. In many cases the same combinations of atoms can produce a crystalline or a noncrystalline structure depending on whether the atoms have enough time during the forming process to arrange themselves in a periodic manner (Bennet, 1986).

The process for making advanced ceramics is remarkably similar in principle to the one by which traditional clay artifacts are made. To mass-produce fired pottery, natural minerals are first milled and blended into a fine clay powder. Water is added to form a plastic mass, which is shaped by conventional techniques such as injection molding, extrusion molding or slip casting. The shaped object is dried in air before being placed in a kiln. There it is fired at a temperature below that at which the ceramic would completely melt, a process called "sintering." During sintering the clay particles are "welded" together so that most of the voids between particles are removed, and consequently the object shrinks.

Most of the current research efforts are aimed at reducing the number and size of flaws normally introduced in ceramic materials by raw material and process variations (Kamo, et al., 1983). The objective of this research is to produce pure, uniform, submicro-sized spherical particles that can be densely packed in an orderly fashion and subsequently sintered at lower temperatures and for shorter times than required at present.

The following is a listing of new advanced ceramic products based on this "perfectly ordered" structure, expected to enter commercial markets prior to 1995, as identified by Johnson, et al. (1983):

- Zirconium-based ceramics will come into widespread use for gas reforming and other high temperature reactions. They will be used for containers and heat exchangers of reaction vessels.
- Solid zirconium also will be used as refractories and electrodes in magnetohydrodynamic generators for very large power stations. And experimental fuel cell power generators using zirconium will be in operation.
- Ceramics will be widely used as dies for drawing and extrusion of metals and other materials, and will see significant use as forming tools in forging and die casting.
- Rechargeable electric power sources will make extensive use of ceramics. For example, high performance ceramics will be used as supports (e.g., nitrides) for the electrolytes, or as the electrolytic membrances (e.g., beta and zeta aluminal) for sodium and lithium systems.
- Large, single crystal ceramics may see widespread use for electronics components.

- Gas turbine engines for cars and trucks will require extensive use of ceramics for high temperature heat exchangers and turbine blades. Ceramic mufflers, brakes and bearings also will be used for vehicles.
- Use of ceramics for transferring, containing and metering molten metals will continue to grow as new and improved methods of smelting and metal processing are developed.
- Porous ceramics will play a large role in environmental control systems, such as sewage treatment and filtering and purifying air and water."

Table 7.2 presents applications of advanced ceramics as substitutes for strategic materials. Extensive use of advanced materials in place of the three metals listed would significantly reduce reliance on the ores that contain these metals. This in turn would alter the geopolitical importance of some countries, such as Zaire, the Republic of South Africa and Cuba. The principal research centres for advanced ceramics are the U.S. Germany and Japan. France and the U.K. have undertaken relatively limited research and development activities in advanced ceramics (Figure 7.2).

The dominance of Japan, Germany and the U.S. in the research and development of advanced ceramics can be readily explained by government policies in these nations which have encouraged activities in this area. In the U.S. such programmes have been

Table 7.2

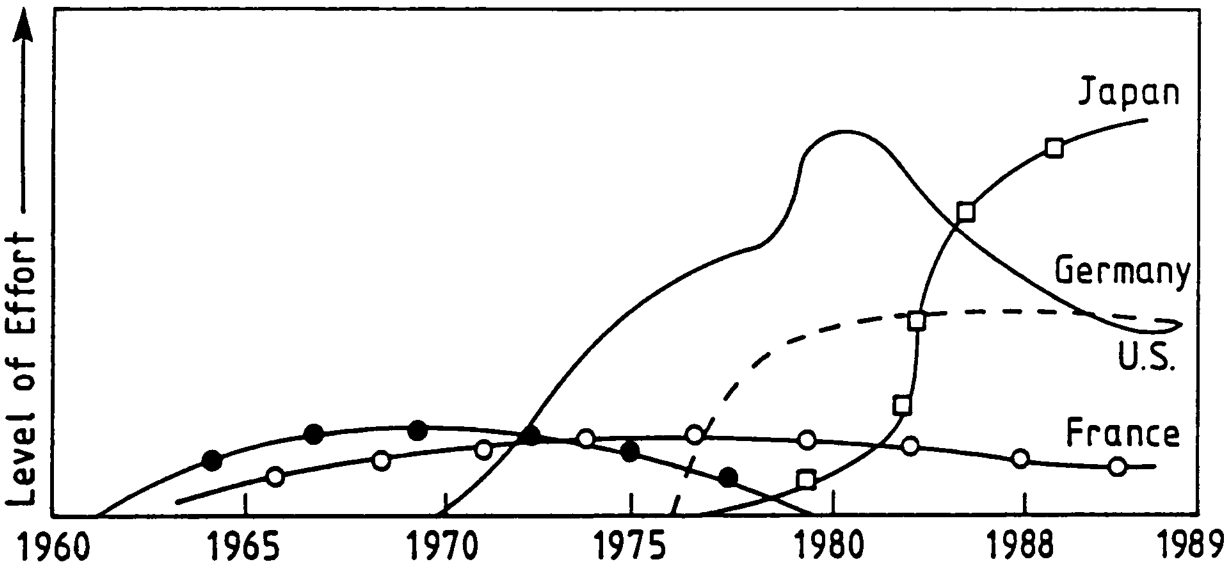
Strategic Materials for Which Advanced Ceramics Could Substitute

Material	Application where Advanced Ceramics May Replace Material	Current Technological Carried for Advanced Ceramics
Tungsten	Wear parts (liners, pads, nozzles, bearings, gates, slides, valves, seals)	Demonstration
	Cutting tools and abrasives	Achieve hardness potential
Cobalt	Diesel combustion parts	Demonstration
	Turbocharger rotors	
	Heat Recovery systems	
Nickel	Diesel combustion parts	Demonstration, properties, maintenance

Source: National Materials Advisory Board, 1985.

Figure 7.2

Generalized Comparison of Advanced Ceramics
Development Activities for Selected Countries
1960 - 1989



Source: Lenoe, E.M. and J.L. Meglen, "International Perspective on Ceramic Heat Engines, Ceramic Bulletin, 1985, 64(2).

principally supported by the DOD. In Germany, the state governments have expanded resources for advanced ceramic research. In Japan, MITI has devoted considerable resources for advanced ceramic research. Conversely, the governments of France and the U.K. have done little to encourage such activities. (See Chapters 8 to 12 for an analysis of these issues.)

7.4.1 Advanced Ceramics Activity in France, Germany and United Kingdom

Advanced ceramics activity in the three selected European nations is limited to laboratory-based R&D activities (NRC, 1987). Most of these laboratories are associated with academic institutions in these three countries. Research and development activities in academic institutions are undertaken by academic scientists, many of whom have become familiar with advanced ceramics R&D in the U.S. or Japan (MITI, 1986). In fact the activities of R&D related to advanced ceramics in France and U.K. serve as training for advanced science studies in academia, rather than representing government or industry directed objectives in this field of advanced science.

In Germany there has been considerable interest in advanced ceramics application in the internal combustion engine by German car manufacturers.

The governments of France and the U.K. have received significant support from German state governments (U.S. DOC, 1984).

7.4.2 Advanced Ceramics Activity in the United States

Ceramic research and development in the U.S. has grown significantly in the past 10 years, with strong industrial interest and forecasts for future commercial growth in the use of advanced ceramics. The National Materials and Minerals Policy Research and Development Act of 1980 in particular, encouraged research in advanced ceramics. The principal centres of advanced ceramics research are presented in Table 7.3.

It can be seen from the information presented that academia, the private sector and government agencies in the U.S. have engaged in advanced ceramics development.

The Defense Advanced Research Project Agency (DARPA) of the U.S. DoD and the U.S. Department of Energy (DOE) are the principal government sponsors of advanced ceramics research.

In 1971, DARPA established what has become known as the DARPA Gas-Turbine Program. The objectives of the programme were to (1) develop an engine system that would operate at a temperature level higher than any using metallic materials; (2) learn how to

Table 7.3

Centres of Advanced Ceramic Activity
in the U.S., 1987

Area of Emphasis

Centre	ZrO_2	SIC	Si_3N_4	Composites	Fine Particules	Electronics
Battelle, Columbia			X	X		
U. of Calif. Berkeley		X	X	X		
U. of Calif. S. Barbara	X			X	X	
Case Western Reserve	X					
Cincinnati			X			
Cornell					X	X
Florida		X	X		X	X
Georgia Tech					X	
Illinois		X	X			X
Lehigh						X
MIT	X	X	X	X	X	
Michigan			X			
Missouri, Rolla						X
N.C. State		X				
Ohio State			X			
Penn State		X		X		X
Rutgers				X		X
Utah			X			
VPI						
Washington		X				
DOE, Argonne		X				
DOE, Lawrence Livermore			X			
DOE, Los Alamos		X	X	X		
DOE, Sandia	X					X
DOE, Oak Ridge	X	X		X		
NBS			X	X		
NASA, Ames		X				
NASA, Lewis		X	X	X		
NRL	X	X	X	X	X	

Source: NRC, 1987

incorporate brittle materials into engine designs; and (3) reduce dependency on strategic materials.

The DARPA programme met most of its objectives. An all-ceramic engine (combustor, regenerator, ducts, stators, and rotors) was designed, built, and operated (NRC, 1987).

In 1976 the DOE and NASA funded the Ceramic Application Turbine Engines (CATE) project to evaluate ceramic stators and rotary heat exchangers in a truck engine operating at a turbine inlet temperature of 1900°F. This programme was successfully completed in 1978 (NRC, 1984).

In 1979 the DOE funded two advanced gas turbine (AGT) programmes. These programmes were to demonstrate high-efficiency automotive gas turbines, capable of using alternate fuels, meeting Environmental Protection Agency (EPA) emission requirements, and being competitive in cost (both initial and life-time), performance, and safety with comparable internal combustion engines.

The AGT programme ended in 1986 with only partial success. A follow-on programme, called the Advanced Turbine Technologies Application Program (ATTAP) was authorized in 1987. It is a 5-year programme aimed at continuing the progress that was made by the AGT programme (NRC, 1987).

In 1982 the Ceramic Technology for Advanced Heat Engines Program was initiated by Oak Ridge National Laboratories (ORNL) at the request of the DOE. Its primary goal was to develop an industrial technology base to provide reliable and cost-effective high-temperature ceramic components for use in advanced heat engines. The programme was designed to develop generic ceramic technology and was not tied to a specific engine design or component (NRC, 1987).

The original ORNL programme plan was for a 5-year period and it received significant funding as shown in Table 7.4. This programme is continuing. The funding for this research originated from the U.S. Federal Government, industry and academia. In addition to the research and development activities undertaken or funded by U.S. Federal Government agencies, several U.S. industrial firms are engaged in such activities.

Table 7.5 lists United States firms engaged in research and development activities related to the use of advanced ceramics by type of activity.

These firms consist of a variety of industrial firms in the U.S. with significant concentrations in the motor vehicle, inorganic chemical, machinery and aerospace sectors.

Table 7.4

United States Government Funding for Advanced Ceramics Research and Development, 1983-1989 (in millions of current dollars)

Fiscal Year	Estimated Funding	Actual Appropriation
1983	2.7	2.42
1984	4.6	4.85
1985	6.3	5.67
1986	10.6	8.08
1987	14.9	12.5
1988	16.9	13.7
1989	10.5	9.6

Source: NRC, 1987

Table 7.5

Major U.S. Firms Engaged in Advanced Ceramic Research, Development and Engineering, 1988

Cutting Tools

Kennametal, Inc.
Carboloy Systems Dept.
GTE Walmet Co.
Teledyne Firth Sterling
Coors Porcelain Co.
Valenite
TRW/Wendt-Sonis
Talide Metal Carbides Corp.
Adams Carbide Corp.
Babcock and Wilcox

Wear Parts

Carborundum Co.
General Electric Co.
Norton Co.
Coors Porcelain Co.
ESK Corporation
ART, Inc.

Engine Design and Development

Ford Motor Co.
Garrett Corp.
Cummins Engine Co.
General Motor Corp.
Westinghouse Electric Corp.
General Electric Co.
International Harvester Co.
Hague International Co.
Terratek, Inc.
Catepillar Tractor Co.
Pratt and Whitney Co.

Ceramic Materials and Parts

Carborundum Co.
Norton Co.
Corning Glass Co.
Coors Porcelain Co.
Ceramtech Inc.
GTE Sylvania
General Electric Co.
Kaman Sciences Corp.
Dow-Corning Co.
United Technologies Corp.
Airresearch Casting Co.
Ceradyne, Inc.
DuPont
Celanese

Source: Industry Analysis Division, U.S. Department of Commerce Printouts, 1988.

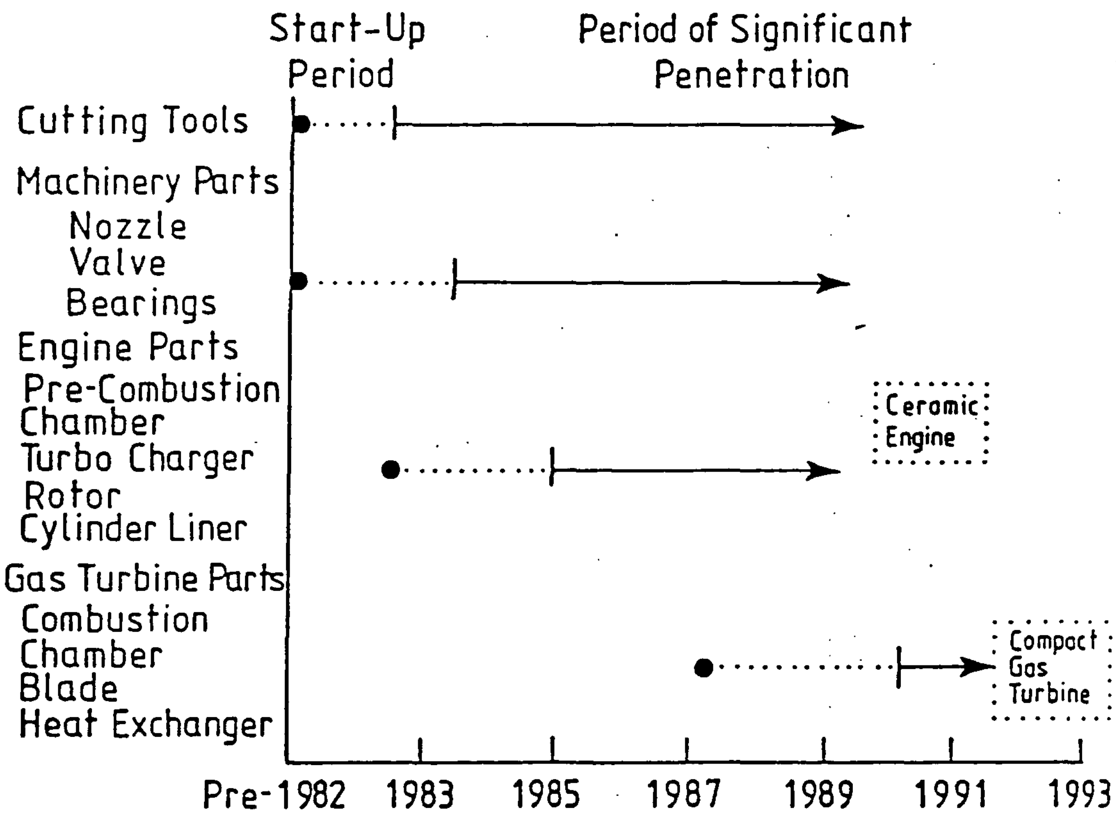
7.4.3 Advanced Ceramics Activity in Japan

Japanese activities in the research, development, engineering and manufacture of advanced ceramics materials began in the early 1970's as a logical outgrowth of the Japanese conventional ceramics industry (Figure 7.3).

Japanese research and development activities in advanced ceramics were accelerated in the late 1970's and early 1980's. In 1981, Japan established two research organizations. The Exploration Research for Advanced Technology and the Research and Development Project of Basic Technology for Future Industries; both of these undertook considerable development efforts in advanced ceramics (MITI, 1986). As of 1988, the Japanese have established eleven centres for the research and development of advanced ceramics (Table 7.6). A large number of advanced ceramics projects are undertaken jointly by Japanese academic institutions and industrial firms (Table 7.7). In addition, a total of some seventy Japanese industrial firms are engaged in advanced ceramics research and development using their own resources (Table 7.8). As in the case of the U.S., Japanese firms engaged in advanced ceramics research represent Japanese motor vehicles, inorganic chemical and machinery sectors. However, because Japan has a well developed ceramics industry, all Japanese ceramics firms are engaged in advanced ceramics research.

Figure 7.3

Evaluation of Japanese Advanced
Ceramics Activities 1982 - 1993



Source: SHC, 1986.

Table 7.6

Centres of Advanced Ceramic Activity
In Japan, 1988

<u>Area of Emphasis</u>

Centre	ZrO_2-	SiC	Si_3N_4-	Composites	SHS	Fine Particlues	Electronics
Kobe Univ. Tokyo		X					
Kyushu Inst. of Tech.			X				
Nagoya U.						X	X
Osaka U.		X	X			X	X
Tohoku U. Sendai		X	X	X			
Tokyo U.						X	
Tokyo Inst. of Tech.	X	X				X	X
GIRI, Nagoya		X	X				
GIRI, Osaka		X	X				
Nat'l Inst. for Research-Inorganic Materials		X	X				
Nat'l Defence Academy							X

Source: MITI, 1986

Table 7.7

Selected Research Projects in Ceramics
Undertaken in Japan, 1986-1988

Project	Research Institute	Company
High-pressure sintering of BN cutting tools	Tokyo Institute of Technology	Nippon Oil and Fats Co., Ltd.
Manufacture of SiC fibre from organic silicon polymers	Tohoku University	Nippon Carbon Co., Ltd.
Manufacture of alumina powder of high purity and high sinterability	Government Industrial Research Institute, Nagoya	Daimei Chemical Industries, Ltd.
Continuous production of high-performance ceramic film	Seikei University	Mitsubishi Mining and Cement Co., Ltd.
Sintering of sialons	NIRIM	Shinagawa Refractories Co., Ltd.
Sintering of high-purity diamond cutting tools	NIRIM	Toshiba Tungalo Co., Ltd.
Gas pressure sintering of silicon nitride	NIRIM	NTG
Vapour-phase synthesis of diamond film under low pressure	NIRIM	Mitsubishi Metals Industries, Ltd.
Ultrafine particles	---	ULVAC Corp.
Amorphous and intercalated compounds	Tohoku University	---
Fine Polymers	Soph University	---
Bioholo	Teikyo University	---

Source: MITI, 1986.

Table 7.8

Japanese Companies Engaged in Research and Development of Advanced Ceramics, 1986

TDK Corporation
Kyocera Corporation
Murata Manufacturing Co., Ltd.
Taiyo Yuden Co., Ltd.
Toshiba Corporation
Toshiba Tunaloy Co., Ltd.
Nippondenso Co., Ltd.
Toyota Motor Corporation
Toyota Central Research and Development Labs., Inc.
Aisin Seiki Co., Ltd.
Hitachi, Ltd.
Hitachi Metals, Ltd.
Hitachi Chemicals Co., Ltd.
NGK-Sparkplug Co., Ltd.
Asahi Chem. Industry Co., Ltd.
Asahi Glass Co., Ltd.
Narumi China Corporation
Fuji Electric Co., Ltd.
Fuji Titanium
Nippon Tungsten Co., Ltd.
Sumitomo Chemical Co., Ltd.
Sumitomo Special Metals
Sumitomo Electric Indus., Ltd.
Isuzu Motors
Tohoku Metal Industries, Ltd.
Matsuhita Electric Components Co., Ltd.
NEC Corporation
Mitsubishi Mining and Cement Co., Ltd.
Mitsubishi Electric Corp.
Mitsubishi Chemical Industries Co., Ltd.
Ube Chemical Industries, Co., Ltd.
Nippon Soda Co., Ltd.
Nippon Carbon Co., Ltd.
Toray Industries, Inc.
Nippon Steel Corporation
Kawasaki Steel Co.
Kobe Steel, Ltd.
Kurosaki Brick Refractories, Co.,Inc.
Narita Seitosho
Toko, Inc.
Hondo Motors Co., Ltd.
Kubota
Ishikawajima-Harima Heavy Industries Co., Ltd.
Shinagawa Refractories Co., Inc.
Toyoda Machine Works, Ltd.
Denki Kagaku Kogyo, Ltd.
Fujitsu
Showa Denko K.K.
Oki Electric Industry Co., Ltd.
Sony Corporation
NTT
Toyo Soda Manufacturing Co., Ltd.
Ibiden Co., Ltd.
Onodo Cement Co., Ltd.
Komatsu, Ltd.
Shin-Etsu Chemical Industries
Chichibu Cement Co., Ltd.
Japan Metals and Chemicals Co., Ltd.
Nippon Kokan K.K.
Noritake Co., Ltd.
Toyo Kogyo Co., Ltd.

Source: MITI, 1986.

7.5 ADVANCED POLYMERS; CHARACTERISTICS, USES AND ASSOCIATED SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES

Advanced polymers are organic chemical compounds consisting of smaller molecular units known as monomers, repeated thousands of times in a chainlike structure.

It was estimated that in 1987 the total worldwide sales of advanced polymers were valued at $1.3 billion. In 1990 the sales are projected to reach $8.3 billion, and in 1995, over $15 billion (NRC, 1987). World production of advanced polymers in 1987 was estimated at about 1100 million pounds (weight), with the electronics sector, consuming 26 percent, the building and construction sector, 10 percent, industrial machinery, 4 percent and the remining 16 percent being divided among such applications as defence-related materials, medical applications, optics, and advanced composites (NAS, 1987).

Figure 7.4 displays the principal advanced polymers in use at the present time (1988).

The information presented shows the basic chemical unit in advanced polymers, the monomer, that is repeated hundreds or thousands of times in the complete polymer chain.

The application of polymers for various industrial uses is increasing at a rapid rate principally because of the feasibility of "designing" very specific polymers for numerous uses. As stated by the National Materials Advisory Board (1985):

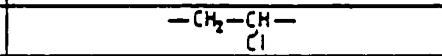
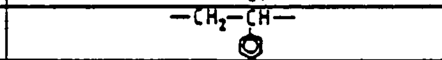
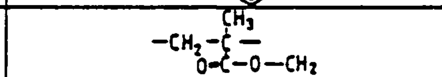
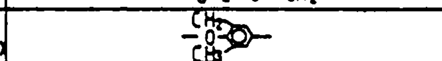
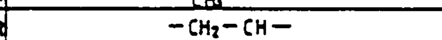
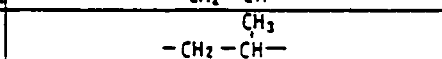
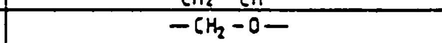
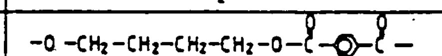
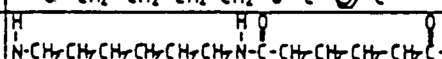
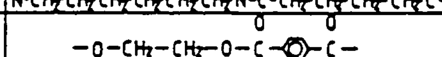
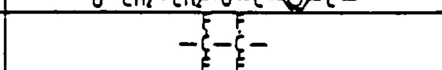
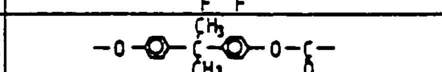
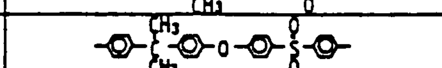
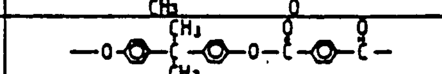
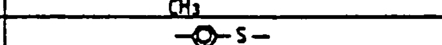
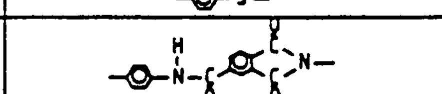
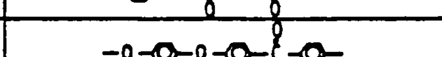
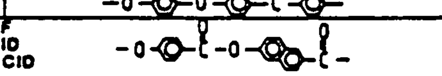
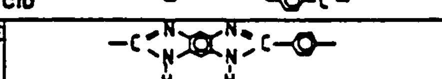
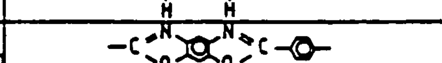
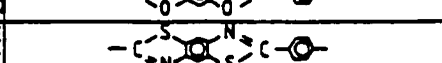
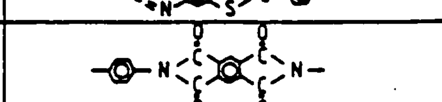
> Polymer science gains its power from the infinite versatility of synthetic polymers. Not only the bulk materials but also their basic constituents, polymer molecules, are tailor-made. The polymer molecule is built from smaller molecular units known as monomers, repeated hundreds or thousands of times in a chainlike structure. The choice of monomers and the way they are assembled shape the properties of the bulk material. The polymer can also be tailored on a larger scale. Like a metal or a composite, it can be given a micro-structure -- for example, an oriented arrangement of molecules or a controlled array of regions that differ in composition. Thus the made-to-order products of polymer chemistry can be further shaped to human wants through polymer processing.

7.5.1 Advanced Polymers in France, Germany and the United Kingdom

Advanced polymer R&D activities and production in France, Germany and the U.K. are carried out by aircraft manufacturing firms and chemical companies. For example in the U.K., British Aerospace, Rolls Royce and ICI have R&D activities in advanced polymers. In Germany, Dornier BASF are the principal centres of advanced polymer activity. CIBA-Geigy and SNIAS perform research and development activities with advanced polymers in France.

Figure 7.4

Selected Advanced Polymers:
Chain Unit and Melting Temperatures

POLYMER	CHAIN UNIT	MELTING TEMPERATURE	GLASS TRANS. TEMPERATURE
POLYVINYLCHLORIDE		—	82
POLYSTYRENE, ATACTIC		—	100
POLYMETHYL METHACRYLATE, ATACTIC		—	105
POLY (2.2 DIMETHYL PHENYLENE OXIDE)(PPO)		—	135
POLYETHYLENE, LINEAR		—	-110
POLYPROPYLENE, ISOTACTIC		138	-10
POLYOXYMETHYLENE		165	-85
POLYBUTYLENE TEREPHTHALATE		180	17
POLYHEXAMETHYLENE ADIPAMIDE		240	50
POLYETHYLENE TEREPHTHALATE		265	70
POLYTETRAFLUORO ETHYLENE		265	-150
POLY (4.4 ISOPROP YLIDENE DIPHENYLENE CARBONATE)		327	149
POLYETHER SULFONE		—	190
POLYARYLATE		—	190
POLYPHENYLENE SULFIDE		285	185
POLYAMIDE-IMIDE		—	MORE THAN 290
POLYETHERETHER KETONE		—	143
AROMATIC COPOLYESTER OF 6.2 HYDROXYNAPHTHOIC ACID AND 1.4 HYDROXYBENZOIC ACID		WIDE RANGE	
POLY(PARA PHENYLENE BENZOBISIMIDAZOLE) (PBO)		DECOMPOSITION TEMPERATURE	MORE THAN 400
POLY(PARA PHENYLENE BENZOBISOXAZOLE)(PBI)		DECOMPOSITION TEMPERATURE	MORE THAN 400
POLY(PARA PHENYLENE BENZOBISTHIAZOLE)(PBT)		DECOMPOSITION TEMPERATURE	MORE THAN 400
POLYIMIDE		DECOMPOSITION TEMPERATURE	MORE THAN 400
POLYPHENYL		DECOMPOSITION TEMPERATURE	MORE THAN 530

Source: Richerson, 1985.

Official production data on advanced polymers in these three countries are not available but estimates place the 1987 production as follows:

France - $70 million;

Germany - $60 million; and

United Kingdom - $70 million (NRC, 1987).

Most of the uses of advanced polymers in these three nations are related to aircraft and machinery manufacture. Motor vehicle production, which in the U.S. represents a significant market for advanced polymers, does not represent an important demand element in Europe (NRC, 1987).

Most of the R&D activities in advanced polymers in these three nations are undertaken by the private sector as government supported advanced polymer activities are limited. One of the principal reasons for this limited government support is the fact that advanced polymers have found limited application in defence-related material in Europe (U.S. DOC, 1984). This is contrary to the U.S. experience where advanced polymer applications in defence goods -- in particular in aircraft -- were the basis for significant advanced polymer research and development (Clark and Flemings, 1986).

The opinion of U.S. scientists engaged in advanced polymer development is that European efforts in this advancing technology are limited at the present time and will continue to be modest in the future (U.S. Congress, 1976; NRC, 1987). Table 7.9 presents a listing of advanced polymer research centres in Europe.

7.5.2 Advanced Polymers in the United States

The available information indicates that the total advanced polymer production in 1987 in the U.S. was valued at $0.9 billion. The principal users of advanced polymers in the U.S. are aircraft manufacturers, machinery and electronics (NAS, 1987). A very large proportion of this output was used in the production of defence-related products, primarily aircraft, and information on this use is not available.

Significant R&D activities occur in advanced polymer areas in the U.S. Most of these are undertaken by U.S. DoD laboratories or are undertaken by private sector laboratories and industrial firms with DoD funding (Table 7.10).

7.5.3 Advanced Polymers in Japan

The estimated production of advanced polymers in Japan in 1987 was $200 million (MITI, 1988). A significant proportion of

Table 7.9

Centres of Research in Structural Polymeric Materials, Europe, 1987

Organization	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
ICI	X		X	X			X	X
RK Textiles	X			X				
AKZO		X					X	X
ENKA	X			X				
DSN					X			
BASF	X			X			X	X
MBB	X	X		X				
Dornier								
British Aerospace	X	X		X				
ELF Acquitaine	X			X			X	X
CIBA-Geigy	X			X				
SIGRI	X			X				
Leeds University	X				X			
Cambridge University		X						
Karslshule								
Max Planck		X	X					
Imperial College of Sci. and Tech.	X			X				
SNIAS (Aerospatiale)	X	X		X				
SEP	X	X		X				
Rolls Royce	X			X			X	X

(A) Composites
(B) Aramids
(C) Thermotropic Liquid Crystal
(D) Carbon Fibre
(E) High-Modulus Polyolefins
(F) Ordered Polymers
(G) High-Performance Thermoplastics
(H) High-Temperature Polymers

Source: NRC, 1987

Table 7.10

Centres of Research in Structural Polymeric
Materials, U.S., 1987

Organization	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Dupont	X	X				X	X	X
Hercules	X			X				
Celenese	X		X		X	X	X	X
Union Carbide	X			X			X	X
Boeing	X	X		X				
AVCO	X							
General Dynamics	X	X		X				
Lockheed	X	X		X				
Northrup	X	X		X				
McDonnell Douglas	X	X		X				
Rockwell	X	X		X				
Martin Marietta	X	X		X				
United Technologies	X	X		X				
Ford	X			X				
Bell Helicopter	X	X		X				
Allied-Signal	X				X			
Dartco			X					
Fiberite (ICI)	X	X		X				
Normco Materials (BASF)	X	X		X				
Celim Carbon Fiber, Inc. (BASF)	X							
Univ. of Delaware	X							
Virginia Polytechnic	X							
U. of Dayton (Research Inst.)						X		
U. of Massachusetts			X		X	X	X	X
M.I.T.	X			X				
Rensselaer Polytechnic Inst.	X							
Air Force (AFWAL)	X	X		X		X	X	X
NASA (Langley, Lewis & JPL)	X			X			X	
Army (MTL)	X							
Navy (NADC)	X							

(A) Composites
(B) Aramids
(C) Thermotropic Liquid Crystal
(D) Carbon Fibre
(E) High-Modulus Polyolefins
(F) Ordered Polymers
(G) High-Performance Thermoplastics
(H) High-Temperature Polymers
Source: NRC, 1987

this production was used in the manufacture of machinery parts and components followed by microelectronic component production (MITI, 1986). A unique aspect of Japanese advanced polymer research and development activities is that most of such activities are supported and undertaken by Japanese industry, with very limited involvement by the Japanese Government (Table 7.11).

There are three frequently reported reasons for the Japanese research and development effort in advanced polymers. Applications in the automotive industry (in automobile body and in engine applications) is one of the reasons for Japanese R&D activities (NRC, 1987). Another is the recognition by the Japanese of the wide range of possible applications of advanced polymers jointly with advanced ceramics to form composites (NIRA, 1987). The third reason for Japanese interest is their applicability in aircraft design, engineering and production and the Japanese emphasis on the aircraft industry as a "targeted" growth sector in Japan (MITI, 1986; Yano Research Institute, 1983).

7.6 COMPOSITES: CHARACTERISTICS, USES AND ASSOCIATED SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES

Composites are the fastest growing advanced materials. The term "composite" refers to a plastic resin that is reinforced with fibres, whiskers or dispersions of another material in a combined form, referred to as matrix. Composites yield an advanced

Table 7.11

Centres of Research in Structural Polymeric Materials, Japan, 1987

Organization	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Toho Rayon	X			X				
Toray	X	X		X				
Teijin		X					X	X
Kurcha	X			X			X	X
Mitsui Petrochemical					X			
Toyoba					X			
Sumitomo Chemical	X			X				
Mitsubishi Heavy Indus.	X	X		X				
Fuji Heavy Industries	X	X		X				
Mitsubishi Rayon	X	X		X				
Mitsubishi Chemicals	X			X			X	X
Mitsui Toatsu								
Industrial Research Inst.-Kyushu (AIST)	X			X				

(A) Composites
(B) Aramids
(C) Thermotropic Liquid Crystal
(D) Carbon Fibre
(E) High-Modulus Polyolefins
(F) Ordered Polymers
(G) High-Performance Thermoplastics
(H) High-Temperature Polymers

Source: NRC, 1987.

material whose performance characteristics combine the strengths of each constituent material.

In the past 20 years a number of composites have been developed, a familiar example of which is fibreglass-reinforced plastics (FRP). The term advanced composites was coined to distinguish materials incorporating the new high-performance fibres and plastic resins, such as polymers from older and conventional composites. The principal types of advanced composites are 1) polymer-matrix composites; 2) ceramic-matrix composites; and 3) metal-matrix composites.

Most advanced composites are designed to take advantage of the enhanced properties of fibres. A bundle of fibres has little structural value. To harness their strength the fibres are embedded in a matrix of another material. The matrix acts as an adhesive, binding the fibres and lending solidity to the material. It also protects the fibres from environmental stress and physical damage.

The strength and stiffness of the composite remains very much a function of the reinforcing material, but the matrix makes its own contribution to properties. The ability of the composite material to conduct heat and current, for example, is heavily influenced by the conductivity of the matrix. The mechanical behaviour of the composite is also governed not by the fibres alone but by a synergy between the fibres and the matrix.

Many of the substances used in the manufacture of composites have very limited physical properties. Indeed these materials may be brittle and weak, such as for example, glass, carbon or silicon. However when such substances are produced as particles and dispersed in a binder to create a composite, the chemical and physical properties of the composite are extraordinary in performance and often exceed that of speciality steels in strength.

The fundamental reason for this extraordinary change in properties is that in small dimensions these substances are less likely to contain major flaws. There exists a statistical base for this change. The NRC (1987) explains this statistical basis as follows:

> "When such a material (glass, boroncarbon, silica, etc.) is produced in the form of particles or fine fibers (the commoner case), its useful strength is greatly increased. Whereas window glass is weakened by its tendency to shatter, similar glass spun into fine fibers has a tensile strength of more than half a million pounds per square inch, or three billion pascals. (A pascal is a force of one newton exerted over an area of one square meter.) The tensile strength of ordinary steel, in comparison, is half a billion pascals. The remarkable increase in strength at small scales is in part a statistical phenomenon: the probability that a sample of material will contain a flaw large enough to cause brittle failure goes down as the same size is reduced. If one fiber in an assemblage does fail, moreover, the crack cannot propagate further and the

> other fibers remain intact. In a similar amount of the bulk material, in contrast, the initial crack might have led to complete fracture.
>
> Tiny needlelike structures called whiskers, made of substances such as silicon carbide and aluminum oxide, also contain fewer flaws and show greater strength than the material in bulk form. Whiskers are less likely to contain defects than the bulk material not only for statistical reasons but also because they are produced as single crystals that have a theoretically perfect geometry."

The potential applications of the composite approach are extremely large (albeit at a laboratory scale) and rapidly increasing. The manufacturing process for advanced composites is relatively complex.

Advanced ceramic composites for example start with a ceramic fibre, which is produced by plasticizing a ceramic powder, extruding it into a fibrous strand, and firing it. The ceramic fibres are usually based on silicon carbide, silicon nitride, aluminum silicate, or a combination of these compounds. The fibres are then embedded in a ceramic matrix (e.g., silicon carbide) to form glass-ceramic composites, metal-matrix composites or plastic-matrix composites.

In addition to the use of glass, carbon, silicon, boron, etc. in composite, "new" composite products based on metal-matrix configurations are being developed. The number of different materials used as matrices and fibres is exceptionally large;

Table 7.12 presents the more common of these used in metal-matrix composites.

It is important to underline the fact that most of the activities related to composites take place in laboratories at the research and design phases. The manufacture of certain composites does take place, but most, if not all of this is limited to defence-related requirements.

7.6.1 Composite Activity in France Germany and the United Kingdom

Research and development activities related to advanced composites in these three countries are limited (NRC, 1987). One of the principal reasons for this limitation lies in the fact that there exist very limited commercial markets for advanced composites, because of the very high cost of these materials. France, Germany and the U.K. have a relatively limited production of defence-related material which requires the use of advanced composites and therefore R&D activities are limited. Table 7.13 identifies the principal centres of research related to advanced composites in these three nations.

7.6.2 Composite Activity in the United States

Some twenty American firms and six academic institutions have undertaken research and development in composites (Table 7.14).

Table 7.12

Materials Commonly Used in
Metal-Matrix Composites

Used As Matrices	Used as Fibres
Aluminum	Carbons
Titanium	Boron
Nickel	Tungsten
Copper	Steel
Magnesium	Silicon Carbide
Nichrome	Borsic
Steel	Nickel
Chromium	Molybdenum
Cobalt	Boron Nitride
Niobium	Alumina/Silica
Tantalum	Zirconium
	Hafnium
	Titanium
	Silicon Nitride
	Titanium Diboride
	Titanium Carbide

Source: Richerson, 1985.

Table 7.13

Organizations Engaged in Composite Research;
France, Germany and United Kingdom, 1987

France

- Ecole des Mines
- Bordeaux University
- Aeronautique a Aerospatiale
- Scoiete National de Powders Explosive
- Institute St. Louis
- Thomson-CFS

Germany

- Messerschmitt-Bolkow-Blohm
- Berghof GmbH
- Batelle-Frankfurt

United Kingdom

- Rolls Royce
- Harwell
- British Aerospace
- Heworth & Grandage
- Imperial Chemicals
- Royal Aircraft Establishment
- Lagstall Engineering Co.
- Wellworthy Limited

Source: NRC, 1987

A major force in these research and development activities is the U.S. DOD and various federal and private laboratories and constractors working for the DOD. Most of the R&D activities undertaken by these organizations are restricted and information on them is not available.

7.6.3 Composite Activity in Japan

Many of the Japanese multiproduct firms and academic institutions are undertaking research, development and engineering activities focused on composites (Table 7.15). There are several major unique aspects of these Japanese R&D activities.

The first of these pertains to the fact that the Japanese composite R&D effort extends Japanese technological achievements in advanced ceramics and, in fact, represents at the present time the terminal area of research in the Japanese ceramic R&D continuum (Yano Research Institute, 1983).

The second pertains to the Japanese effort to merge advanced ceramics "know how" with composite technology. The third consists of the Japanese effort to transfer U.S. composite technology to Japan via a series of cooperative aircraft production arrangements (NRC, 1987). Chapter 12 examines these issues in detail.

Table 7.14

United States Firms and Academic Institutions
Engaged in Composite Research, 1984

- Dupont
- Hercules
- Celanese
- Union Carbide
- Boeing
- AVCO
- General Dynamics
- Lockheed
- Northrup
- McDonnell Douglas
- Rockwell
- Martin Marietta
- United Technologies
- Ford
- Bell Helicopter
- Allied-Signal
- Dartco
- Fiberite (ICI)
- Narmco Materials (BASF)
- Celim Carbon Fiber, Inc. (BASF)
- University of Delaware
- Virginia Polytechnic Institute
- University of Dayton (Research Inst.)
- University of Massachusetts
- M.I.T.
- Rensselaer Polytechnic Institute

Source: U.S. DOC, 1984

Table 7.15

Japanese Firms and Academic Institutes
Engaged in Composite Research
and Development, 1987

Firms

- o B&W Refractories
- o Honda
- o Toyota
- o Daia Vacuum Engineering Company
- o Mitsubishi
- o Sumitomo
- o Nippon Carbon
- o Turay
- o Kurcha
- o Mitsubishi Heavy Industries
- o Mitsui Toetso
- o Tokai Carbon
- o Art Metal Manufacturing Co.
- o Toray
- o Toho Besion
- o Kureha
- o Toshiba
- o Toyoda
- o Asahi

Academic Institutions

- o Tokyo University
- o Tokyo Institute
- o Hiroshima Institute of Technology
- o Kyoto University
- o Tokoku University
- o Wasede University
- o Tohica University

Source: NRC, 1987.

7.7 SUMMARY

The advanced materials industry is somewhat unique among advanced technology activities in that this industry truly comprises an emerging technology. Worldwide sales of advanced materials products in 1988 were estimated at only $19 billion. Most of these sales took place in the U.S., and most of the purchasers were defence-related U.S. firms.

The commercial production of the bulk of advanced materials in the past has been undertaken for military equipment. Advanced material products are costly and with some exceptions are currently used in defence-related applications where the superior technical attributes of these materials warrant their use. A significant proportion of research and development activities related to advanced materials is therefore supported by U.S. defence agencies such as DARPA, the U.S. Office of Naval Research and others.

The available information suggests, however, that the almost exclusive use of advanced materials in military equipment is rapidly changing and that the application of advanced materials in civilian sectors will increase at a accelerated rate. The projections of world-wide advanced material sales of $46 billion in 1990 and $88 billion in 1995 attest to the changes in the applications of advanced materials.

Support for this can be also seen from the research and development activities undertaken by academic institutions and industry in the U.S. with their emphasis on such civilian sector uses of advanced materials as medical instruments, structural components for machinery, internal combustion engines, hand tools and various metal cutting and shaping surfaces.

With the exception of advanced ceramics, academic institutions and industry in the U.S. dominate research and development activities in advanced materials. The Japanese ceramics industry, with a very long history in the development of ceramic products, has a distinct advantage over other nations in the application of advanced ceramics products.

There are some research and development activities related to advanced materials undertaken in academic institutions in France, Germany and the U.K., but these are mostly limited to theoretical investigations of the properties of advanced materials. Applied research and development as related to advanced materials are essentially limited to the U.S. and Japan.

As of 1989, the U.S. has a distinct comparative advantage in the research, development and production of advanced materials. The superior technical attributes of advanced materials and potentially very extensive use of such materials force other industrial nations to either develop their indigenous advanced material technology or to purchase the advanced materials technology or products from the U.S.

As of 1989 only Japan has made a deliberate and extensive effort to obtain advanced material technology from the U.S. This effort has been traditional for Japan. The Japanese government and Japanese firms have approached U.S. enterprises engaged in the research, development and production of advanced material with proposals for either co-production or outright purchase of advanced materials technology including patents and engineering as well as manufacturing information. Neither the Japanese Government nor Japanese firms have expressed an interest in the purchase of advanced material products per se. Rather the Japanese focus has been on obtaining the technologies required to manufacture advanced materials products in Japan.

None of the other countries has expressed a significant interest in the advanced materials technology developed in the U.S. It is reasonable to expect that the economies of industrial nations will be affected by the further growth of the advanced materials industry. The impacts from advanced materials technology will affect most industrial sectors with specific effects on the metalworking sectors of the economy.

Further development of advanced materials and a reduction in the cost of advanced materials will also have geopolitical implications. Because advanced materials are superior substitutes for many speciality metal products and applications, nations that supply ores of minor metals for the production of speciality metals will be affected by the growth of advanced materials. Nations that are providers of minor metal ores (Zimbawe, Congo, Canada) may be forced to significantly reduce production of these ores. Further discussion of these geopolitical implications is provided in Chapter 13.