

Durham E-Theses

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

Ivars Gutmanis

How to cite:

Gutmanis, Ivars (1990) On the advancement of science and technology among nations: the importance of government policies upon the development of advanced technology industries in five countries. Doctoral thesis, Durham University.

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a <https://etheses.durham.ac.uk/id/eprint/6272/> is made to the metadata record in Durham E-Theses
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full Durham E-Theses policy](#) for further details.

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

Two Volumes

Volume II

IVARS GUTMANIS

A thesis submitted to the University of Durham
for the degree of Doctor of Philosophy

Faculty of Social Sciences

1990

The copyright of this thesis rests with the author.
No quotation from it should be published without
his prior written consent and information derived
from it should be acknowledged.



25 JUN 1991

CONTENTS

Volume II

8.	SCIENCE, TECHNOLOGY AND INDUSTRY POLICIES IN FRANCE	394
8.1	INTRODUCTION	394
8.2	SCIENCE, RESEARCH AND TECHNOLOGY PERFORMANCE IN FRANCE	401
8.2.1	Government Laboratories	404
8.2.2	University and Grandes Ecoles Research Institution	409
8.2.3	Regional and Local Research Institutions	411
8.2.4	Research Activities by French Industrial Firms	413
8.3	HISTORIC PERSPECTIVE OF FRENCH SCIENCE, TECHNOLOGY AND INDUSTRY POLICIES	416
8.4	PRESENT FRENCH SCIENCE AND TECHNOLOGY POLICIES	424
8.4.1	Financial Assistance for Exports	433
8.4.2	Regulations of Foreign Investments	434
8.5	GOVERNMENT SUPPORT FOR ADVANCED TECHNOLOGIES IN FRANCE	436
8.5.1	Microelectronics Sector	436
8.5.2	French Policies to Advance the Machine Tools Industry	443
8.5.3	French Government Policies in the Advanced Materials Sector	436
8.6	CONCLUSIONS	450
9.	SCIENCE, TECHNOLOGY AND INDUSTRY POLICIES IN GERMANY	452
9.1	INTRODUCTION	452

Theo's
1990/Gur

9.2	INSTITUTIONAL SETTING IN GERMANY	453
9.3	SCIENCE, RESEARCH AND TECHNOLOGY RESOURCES IN GERMANY	455
9.3.1	Higher Education Institutions	456
9.3.2	German Government Research Establishments	457
9.3.2.1	Research Institutions Subordinate to Independent Coordinating Organizations	459
9.3.2.2	German Government's National Laboratories	464
9.3.2.3	Research Establishments Subordinate to German Federal and Laender Ministries	465
9.3.3	Research Facilities Operated by German Industry	466
9.3.4	Conclusions	469
9.4	FUNDING PATTERN FOR SCIENCE AND TECHNOLOGY IN GERMANY	471
9.5	GOVERNMENT SUPPORT FOR ADVANCED TECHNOLOGIES IN GERMANY	476
9.5.1	Support to the German Microelectronics Sector	476
9.5.2	German Policies in the Machine Tools Sector	478
9.5.3	Government Policies in the Advanced Materials Sector in Germany	481
9.6	CONCLUSIONS	482
10.	SCIENCE AND TECHNOLOGY POLICY IN THE UNITED KINGDOM	486
10.1	INTRODUCTION	486
10.2	SCIENCE, RESEARCH AND TECHNOLOGY PERFORMANCE IN THE U.K.	489

10.2.1	Universities	490
10.2.2	Government Laboratories	494
10.2.3	Industry	496
10.2.4	Private Nonprofit Institutions	500
10.3	GOVERNMENT FUNDING AND ASSISTANCE FOR SCIENCE AND TECHNOLOGY ACTIVITIES IN THE UNITED KINGDOM	501
10.4	RECENT SCIENCE POLICIES IN THE UNITED KINGDOM	508
10.5	THE UNITED KINGDOM GOVERNMENT'S SUPPORT FOR ADVANCED TECHNOLOGIES	513
10.5.1	Microelectronics Sector in the U.K.	513
10.5.2	Government Assistance to the Machine Tool Sector in the U.K.	523
10.5.3	U.K. Government Policies for the Development of Advanced Materials	529
10.6	CONCLUSIONS	529
11.	SCIENCE AND TECHNOLOGY POLICIES IN THE UNITED STATES	537
11.1	INTRODUCTION	537
11.2	SCIENCE AND TECHNOLOGY PERFORMERS IN THE UNITED STATES	546
11.2.1	Universities and Colleges	547
11.2.2	Federally-Funded Research and Development Centers	550
11.2.3	In-House U.S. Government Research and Development Facilities	551
11.2.4	National Science Foundation	554
11.2.5	Department of Defense	555
11.2.6	Department of Energy	556

11.2.7	National Aeronautics and Space Administration	556
11.2.8	Industry Sector Laboratories	557
11.2.9	Independent Nonprofit Research Institutions	557
11.3	U.S. FEDERAL GOVERNMENT'S SCIENCE AND TECHNOLOGY POLICIES	558
11.4	U.S. GOVERNMENT SUPPORT FOR ADVANCED TECHNOLOGIES	575
11.4.1	U.S. Government Policies in the Microelectronics Industry	575
11.4.1.1	Very High Speed Integrated Circuits (VHSIC) Programme	582
11.4.1.2	SEMATECH	584
11.4.1.3	Microelectronics and Computer Technology Corporation	586
11.4.2	Machine Tool Industry in the United States	587
11.4.2.1	Department of Defense	589
11.4.2.2	National Aeronautics and Space Administration	590
11.4.2.3	National Science Foundation	590
11.4.3	U.S. Government Policies in Advanced Materials Sectors	591
11.5	CONCLUSIONS	592
12.	JAPANESE GOVERNMENT POLICIES	605
12.1	INTRODUCTION	605
12.2	SCIENCE, RESEARCH AND DEVELOPMENT AND INDUSTRY POOL IN JAPAN	612
12.2.1	Higher Educational Establishments	612
12.2.2	Industry	613

12.2.3	Nonprofit Research Institutes in Japan	616
12.3	JAPANESE GOVERNMENT AGENCIES RESPONSIBLE FOR SCIENCE, TECHNOLOGY, RESEARCH AND DEVELOPMENT POLICY FORMULATION	617
12.3.1	The Economic Planning Agency (EPA)	621
12.3.2	The Ministry of International Trade and Industry (MITI)	621
12.3.3	The Ministry of Finance (MOF)	630
12.4	JAPANESE GOVERNMENT POLICY TOOLS TO ADVANCE SCIENCE, TECHNOLOGY AND INDUSTRY	631
12.4.1	Anti-Foreign Competition Policies by Japanese Government	635
12.4.1.1	Home Market Protection	635
12.4.1.2	Formal Barriers to Trade	636
12.4.1.3	Nontariff Barriers	638
12.4.1.4	Closed Government Procurement	638
12.4.1.5	Administrative Guidance	640
12.4.1.6	Restrictions to Foreign Direct Investment	640
12.4.2	Japanese Domestic Industry Support Policies	641
12.4.2.1	Direct Grants for Research and Development	642
12.4.2.2	Government Sponsored R&D Projects	642
12.4.2.3	Cooperative Research Associations	643
12.4.2.4	Control Over Technology Licensing	644
12.4.2.5	Special Tax Measures for R&D	644
12.4.2.6	Export Incentives	645

12.4.2.7	Antitrust Exemptions	645
12.5	JAPANESE GOVERNMENT POLICIES FOR ADVANCED TECHNOLOGY SECTORS	646
12.5.1	Microelectronics Sector	646
12.5.1.1	MITI's Modus Operandi in the Microelectronics Sector: Cooperative Research Projects	653
12.5.2	Japanese Government Policies to Advance the Machine Tools Sector	659
12.5.3	Advanced Materials Sectors in Japan	665
12.5.3.1	The Role of the Japanese Government in The Advanced Materials Sector	666
12.6	CONCLUSIONS	669
13.	ANALYSES AND CONCLUSIONS	680
13.1	INTRODUCTION	680
13.2	SUMMARY OF GOVERNMENT POLICIES	681
13.2.1	France	681
13.2.2	Germany	688
13.2.3	The United Kingdom	690
13.2.4	The United States	694
13.2.5	Japan	702
13.3	ORIGIN AND GEOGRAPHIC DIFFUSION OF ADVANCED TECHNOLOGY INDUSTRIES	705
13.4	SUMMARY OF THE "NEW" ECONOMIC THEORY	712
13.5	SUMMARY OF CONCLUSIONS	716

14	PROSPECTS	724
	APPENDIX A: ACKNOWLEDGEMENTS	726
	APPENDIX B: GLOSSARY	733
	APPENDIX C: BIBLIOGRAPHY	746

CHAPTER 8:
SCIENCE, TECHNOLOGY AND
INDUSTRIAL POLICIES IN FRANCE

8.1 INTRODUCTION

By some measures, the French economy has performed well during the last few decades. From 1967 to 1988, France's economy grew an average 3.3 percent a year, a rate higher than that for Germany (2.8 percent); the U.S. (2.6 percent); or the U.K. (2.2 percent); but lower than Japan (5.3 percent). Real GNP per person increased in France from \$9,317 in 1967 to \$15,853 (in constant 1987 dollars), during the same time period.

The performance of the French economy, in spite of these growth rates, has been mixed. The French economy has severe structural problems, centred on the production plant of French industry, specifically on the old technology employed in many of the French industrial establishments. As the result of the old capital stock used, there has been a noticeable decline in French industrial productivity (Balassa, 1985). France's productivity growth rates, adjusted for infusions of new capital and henceforth for the use of advanced technologies, averaged 5.1 percent in the 1951 to 1973 period; 3.2 percent in the 1973 to 1979 period; and 2.4 percent in the 1979-1986 period.

French merchandise trade has had a negative balance in all except six years between 1960 and 1988. The last year France had a current account surplus in merchandise trade was 1986 and the surplus was a relatively insignificant \$2.9 billion. In 1987, France's merchandise trade showed deficits of \$3.1 billion and in 1988 this deficit was estimated at \$3.0 billion. France's share of the world's exports has remained essentially the same over the last twenty years. In 1967, France's share of world exports in value terms was 6.5 percent; 8 percent in 1979 and 6.7 percent in 1988. By comparison, Germany's world market share increased from 11 percent to 14 percent during the same time period; in the United Kingdom it declined from 9 percent in 1968 to about 6 percent in 1987. Conversely, Japan's share increased from about 7 percent in 1968 to 19 percent in 1987.

France's mixed economic performance over the last two decades took place during a period when the French government's expenditures focused on economic improvement were increasing considerably. France's government deficit in 1977 was FFr. 18.3 billion; in 1987 it had increased to FFr 150 billion and in 1989 it is estimated at FFr 100 billion. Much of these public expenditures were made to improve France's technological base, but with very modest results (Crafts, 1984; Chavaron, 1989).

The advancement of science and technology in France in spite of large government expenditures has been at best moderate as

witnessed by most indicators of science and technology trends. French scientists have been responsible for some notable scientific discoveries since World War II, though these breakthroughs have not significantly advanced France's technological and industrial growth (O'Brien and Keyder, 1978). In fact the growth of advanced technology industry sectors in France has been very modest.

Several uniquely French policy characteristics partly account for this modest performance. Detailed analyses of these are presented in the following sections, however, it is worthwhile identifying these at the outset. French science, technology, industry and economic policies are formulated and exercised at the highest echelons of the French government. Most of these policies are directed to large industrial establishments, owned or controlled by the French government. Certainly, most of the financial assistance provided by the French government to industry, is earmarked for government controlled enterprises. French firms not controlled by the government, a large proportion of which are small or medium sized, receive very limited assistance although all are affected by various policies and regulations promulgated by the French government, and tailored for the large industrial entities. The small or medium sized firms in France have very limited opportunities to contribute to industry policies before these are issued and the French government makes little or no attempt to build a consensus for the policies

promulgated (Gilpin, 1968; EEG, 1986). These policies are designed and implemented by a large cadre of high-level French bureaucrats or "fonctionnaires", the "Grands Corps" of the French government, employed in some eleven departments and agencies, so-called "bureaus." Most, if not all, of these fonctionnaires remain civil servants for all their professional lives. They have no opportunity to broaden their knowledge outside French government offices and their industry experience is limited to the large, government controlled industrial enterprises. Essentially all are graduates from the three academically prestigious schools in France -- the "Grandes ecoles," far removed from other French academic institutions, from business and from industry (O'Brien and Keyder, 1978). These French officials have limited interest in the smaller enterprises and have no interest in seeking information, guidance or advice from the small or medium sized firms.

These elite French civil servants are committed to "grandeur" types of policies enacted in numerous "grands programmes" -- large and expansive science and technology projects undertaken by government controlled firms but with specific objectives (OECD, 1985).

The principal overriding objective of all these projects has been to retain French control, if not ownership, of advanced technology industries in France, or to recapture the French domestic market for advanced technology goods (Zuscovitch, 1985).

One of the principal policies the French fonctionnaires have consistantly used to retain control of industry sectors has been the nationalization of key industry sectors in France. As a result of this, most of the advanced technology firms in France are fully or partly owned, and certainly controlled by the French government. The design and execution of the grands programmes by the French civil service has also been tailored to retain French control of the industry sectors to which these projects have been applied (Gilpin, 1968).

This desire of the French government to control advanced technology industries in France has resulted in a set of policies which in turn have had an adverse impact on the advancement of French science and technology.

To begin with, French science and technology policies emphasize the supply or production side of advanced technology goods, with very limited attention paid to the demand for such products. For those industry sectors where the producers, i.e., the French government, could dictate the specifications of the products, the demand for such products and the diffusion of technology throughout the French economy has been very good. Such has been the case, for example, with French governmental policies to develop and apply digital communications for the French telephone and communications services owned and operated by the French government (Macioti, 1986; Farnour, 1983).

Demand for advanced technology products and the diffusion of technology for products which are based on market decisions by users -- in particular users that comprise the small size enterprises in France rather than French government edicts, has remained poor. For example, a large scale government project to diffuse computers specified by the French government and manufactured in France throughout the French economy was essentially a complete failure because the potential users of these systems, the French industrial and service establishments, preferred imported computer systems, such as an IBM system 360. Furthermore sales of French advanced technology products in world markets where demand rather than supply determines the sales potential have been weak. However, analyses of the content of these French exports, indicate that a significant portion of these are manufactured in France, but are products of foreign firms or multinational firms located in France. Furthermore, for some of these export products, certain modifications must be made in order to make these compatible with international standards and therefore eligible for export markets ("Economist", 10 December 1988).

A number of the French government's technology and industry policies therefore have been designed to attract foreign firms to France in order to acquire foreign technologies. Indeed, among the many and varied industry policies the French government has introduced since the end of World War II to improve the industrial base in France, policies which offer significant benefits for

foreign firms to locate in France, have been continuous and visible (Friedman, 1983; Northcutt and Rogers, 1985). Typically, various types of agreements have been made to allow French civil servants to have certain control over these foreign firms with the conditions set forth by the French government in return for permission to operate on French soil (Balassa, 1985).

Government policies in France have also included both the protection and the promotion of key French native industrial sectors through a wide variety of mechanisms. These have included financial subsidies of many types, price controls, the encouragement of mergers to achieve economies of scale and therefore market power, export promotion and import restrictions. The ownership, complete or partial, of many, if not most, French industrial firms by the French government facilitates the implementation, but not necessarily the results of these French government policies (Dunning, 1977; Rendeiro, 1984).

Not all of French industry is government owned. For example, the aircraft manufacturer, Aerospatiale, operates with essentially no government involvement in day-to-day operations, but most of the larger firms are controlled by the government.

In conclusion, as in Japan, French government policies are centralized within an elite bureaucracy that has considerable autonomy in shaping science, technology and industrial policies.

Unlike Japan, the French industrial and government bureaucracy focus on the large government controlled enterprises. No attempt is made to undertake dialogues with industry executives of the smaller and medium sized firms, labour, the public or academia.

8.2 SCIENCE, RESEARCH AND TECHNOLOGY PERFORMANCE IN FRANCE

The principal components of the French scientific, research and related activities pool in France are the French government laboratories and research institutions belonging to French national research establishments such as the National Centre for Scientific Research (CNRS), the French Space Agency (CNES), the Atomic Energy Commission (CEA) and other national research institutions.

These are large establishments with large staffs. For example, the CNRS employs 10,000 scientists and 15,000 other staff, while the CEA has 6,000 employees. All of the employees of these establishments are French civil servants, working exclusively for national research institutes with no work experience in other research institutions of any kind. From time to time these scientific and technical fonctionnaires are joined by civil servants from grandes ecoles. In some French government funded projects, particularly those which focus on the research and development of industrial technologies (so-called "programmes mobilisateurs") scientists from other French universities (other

than grandes ecoles) may participate. Such occurrences are not common.

The second important research and development performing group in France consists of universities and the three grandes ecoles. The three grandes ecoles dominate the management and administration of research and related activities. The French universities undertake the actual scientific and related research. There exists in France a wide gap between grandes ecoles and universities, as stated in a 1985 report by the OECD.

Dualism in the French educational system is a core element that perpetuates the cleavage between research, education and industry. On one side universities, which conduct most of the research, carry low prestige in industrial circles and attract little attention; firms therefore often hesitate to recruit university graduates for the most promising careers. On the other, the engineering schools, and especially the "Grandes Ecoles," creates a caste with privileged access to key positions of industrial power in major firms. The caste can only serve as a career restraint, and a block on the ambitions of those educated elsewhere. It certainly hinders the integration of university researchers into industry. Despite timid attempts to remedy the situation, not only do the groups form two separate communities, but the inadequate research training for engineers in France means that those with the greatest ability in abstraction and analysis are not always tuned toward a research mentality and R&D strategies.

The excessive separation between the public research institutes and the educational system further limits the flow of expertise from research to education, and in turn to industry. There is no role for research centres or individual researchers without teaching responsibilities. However, a closed research system without substantial teaching functions cannot effectively transmit or diffuse the knowledge it creates. As experience in other countries demonstrates, students who pass into industry retain ties with research faculties which serve as channels of knowledge later.

The third components of the science and technology performing group in France are the research institutions operated by the regional organizations and local authorities. Until the late 1970s these were of very limited importance in French scientific endeavours. In the last decade, however, research institutions or "technopoles" have been established by French regional and local authorities such as the Zone for Innovation and Scientific and Technological Realisations (ZIRST) at Meylan located in Grenoble. These have the potential to become important and, indeed, have to become more important in future technology activities.

The fourth components of the French science and technology pool are the firms in the private industrial sector and nationalized companies. The nationalized companies participate and contribute to French science and technology activities by being invited to become members of the various grandes programmes. The firms in the private industrial sector undertake only modest research and development activities in France (Cuneo and Mairesse, 1983). As stated in an OECD report ". . . the share of technical research funding borne by (such) firms is less than in the leading industrial countries. The same applies to the volume of research carried out by these same firms . . ." (OECD, 1985).

This structure of the French science and technology pool has remained unchanged since the end of World War II, in spite of

significant differences in the political philosophies of the various French governments since then.

The following presents salient information on the four types of institutions which perform science and technology activities in France.

8.2.1 Government Laboratories

The most important French government scientific and research agencies with responsibilities for the conduct and support of research and technological development are listed in Table 8.1. Their relative importance can be seen by comparing their budgets (Table 8-2). The non-defence government agencies with the largest research programmes are the CEA and the CNRS. Of the three, the CNRS has the primary role in the performance of research and development activities.

The CNRS, established in 1973, is the largest French government supported research organization. The CNRS responsibilities were defined by a government decree of 1982 in which it was required to:

". . . evaluate and carry out, directly or indirectly, any research in the interest of science and of France's economic, social, and cultural progress; contribute to the application and valorization of the results of this research; develop scientific information, encouraging

TABLE 8.1

Principal French Government Science Organizations, France

National Centre for Scientific Research	CNRS
National Centre for Space Studies	CNES
Atomic Energy Commission	CEA
National Agency for the Valorization of Research	ANVAR
National Institute for Agricultural Research	INRA
National Institute for Health & Medical Research	INSERM
Overseas Science and Technology Research Agency	ORSTOM
Tropical Agronomy Research Group	GERDAT
French Agency for Rational Use of Energy	AFME
Bureau of Geological and Mining Research	BRGM
French Research Institute for the Exploitation of the Sea	IFREMER

Source: CNRS, Annual Report, 1987.

TABLE 8.2

Civilian Research and Technology Budget, France, 1985
(in billions of FFr)

<u>Ministry of Research</u>	<u>1985</u>
CNES	(See PTT, below)
CEA	2,198.1
CNRS	2,051.8
ANVAR	910.3
INRA	410.0
INFREMER	435.4
INSERM	510.0
Pasteur Institutes	134.0
ORSTOM	172.0
GERDAT	115.0
AFME	330.0
Research Project Funds*	<u>89.6</u>
	8,526.1
 <u>Ministry of Industry</u>	
BRGM	83.3
Other	<u>17.0</u>
	100.0
 <u>Post, Telephone and Telegraph</u>	
Capital Equipment	1,150.0
Electronics	1,898.9
CNES	3,421.0
Other	<u>337.0</u>
	6,806.9
 <u>Other Ministries</u>	<u>4,984.7</u>
 TOTAL	 20,418.0

* Support for International Research Centres and Programmes.

Source: CNRS, Annual Report, 1987.

the use of the French language; contribute to training for and through research; and set national science policy in light of current and future trends in the national and international scientific situation." (EEC, 1985)

The CNRS scientific programme is carried out by research units operated directly by the CNRS as well as in association with university laboratories, the grandes ecoles, and other government organizations. Its current staff of 25,000 includes 10,000 researchers and 15,000 technical and administrative support staff. At the operating level, the CNRS has a National Science Research Council, with 45 disciplinary panels. These panels have been responsible for recommendations on the programmes, funding, and personnel actions of every CNRS laboratory. In 1986, the CNRS had a total budget of 7.6 billion francs. The budget breakdown by programme and expenditure is shown in Table 8.3.

The CNRS is organized into seven scientific departments, two national institutes (the National Institute for Astronomy and Geophysics and the National Institute of Nuclear Physics and Particle Physics), and four (primarily administrative) directorates. The seven scientific departments of the CNRS and their share of the CNRS budget are:

Life Science	25.5%
Chemistry	15.6%
Humanities and Social Sciences	13.9%
Nuclear and Particle Physics	12.3%
Earth, Ocean, Atmospheric and Space Science	11.6%
Mathematics and Basic Physics	11.4%
Physical Sciences for Engineering	8.3%

TABLE 8.3

Budget of National Centre for Scientific Research
(CNRS), France, 1986
(in billions FFr)

Programmes Financed	1,288.8
Energy	227.1
Biotechnology	400.9
Electronics Services	245.6
Third World	296.2
Employment-Conditions	74.2
French-Scientific Culture	9.4
Material Industry	34.9
Fundamental Research	3,888.0
Final (Applied) Research	1,445.1
Technology Development Programmes	---
Indirect Resources	<u>1,011.3</u>
 TOTAL FUNDING	 7,663.4

Source: CNRS, 1987.

The remaining 1.4 percent of the CNRS budget is allocated to interdisciplinary programmes.

The CEA is the second largest research organization in France. Its basic function is to promote the use of nuclear energy in science, industry and defence.

The CEA in 1986 had a total staff of about 2,000, of which about 60 percent consisted of professionals. In 1986, the total CEA total budget was 4.8 billion francs, of which 65 percent was allocated for programme and equipment authorizations.

In addition to these agencies, French government funded scientific, research and technological activities in France are undertaken by several major national research facilities which are jointly operated by the CEA's Institute for Fundamental Research and the CNRS's National Institute of Nuclear Physics and Particle Physics.

8.2.2 University and Grandes Ecoles Research Institutions

University based science, technology and research activities are limited in France. An exception to this is the research undertaken by university science and engineering faculties at various laboratories operated by the French government. CNRS-operated laboratories are the most important of this group and are

located on French university campuses. These provide opportunities for French scientists to participate in the French government sponsored and funded research.

The principal CNRS laboratories are located at the Universities of Paris, Strasbourg, Grenoble, Lyon, Lille, Montpellier, Rennes, and Toulouse. In addition to these large CNRS laboratories, in 1987 the CNRS operated and funded some 1000 smaller research establishments, most of which are located near French universities.

These French government funded CNRS research establishments in proximity to French universities provide the faculties of these universities with very important opportunities to engage in science, technology and research activities.

A study by Zuscovitch (1985) evaluating the status of French science noted the following on this issue:

Without these government institutions, university research, the conditions of work in which have deteriorated steadily over the past 20 years, would have been able neither to hold its own nor to maintain modern scientific teaching at a high level. These research institutions have enabled French scientists to make important discoveries on many fronts.

Some research and related activities in France are undertaken by the three grandes ecoles, the Ecole Polytechnique (science and engineering), the Ecole Normale Supérieure (academic personnel), and the Ecole Nationale d'Administration (government officials). The emphasis in grandes ecoles, is however, not on research per se, but on management and administration and, of course, on public policy theory and practice. The student body in the grandes ecoles are comprised entirely of French civil servants.

8.2.3 Regional and Local Research Institutions

Regional and local research institutions were not a factor in France prior to 1982. Legislation passed in that year, under President Mitterand, provided the basis for regional and local research institutions. The Policy and Planning Act for Research and Technological Development of July 15, 1982 provides provisions for regional science and technology policies defined as follows:

"As part of regionalised planning and site location plans, the region shall define and develop regional technology poles and shall determine programmes of regional interest over several years ahead.

The region shall be involved in formulating national research and technology policy and shall participate in implementing it. The region shall be particularly responsible for the dissemination and development of new technologies, training, scientific and technological information, for improving existing technologies, for decompartmentalising research and for integrating it within the economic social and cultural development of the region" (EEC, 1986).

These provisions for the development of scientific and technical resource bases in various regions of France are surprising in the light of a long standing and almost sacred French belief in the centralisation of government science and technology activities. This Act is, of course, the result of French political changes in 1981. Furthermore, it represents only one of several science and technology regionalization initiatives undertaken during the 1980's by the French government. A network of research, development and technology advisers (the ARIST's) established in 1982 represents another French government attempt to decentralize science and technology activities in France. Other examples are the establishment in various regions of France, of Centres for Technology Transfer (CRITTs); and the establishment by the French Ministry of Research and Technology of regional offices (DRRI) which act as a liaison between the various regions and French government departments and agencies; and the implementation of "Contrats de Plan Etat-regions".

The results of the French regional science and technology centres in terms of research and related activities undertaken, appear promising, but the history of these establishments is not sufficiently long to reach conclusions as to their impact on French science and technology activities.

8.2.4 Research Activities by French Industrial Firms

A distinction must be made between research activities undertaken by French industrial firms and those undertaken by private and nationalized firms.

French private firms conduct limited research and development activities. Many of these are small establishments, described by many as "backwards" and with limited technical capacity (Chavaron, 1989; Auquier, 1980; OECD, 1985). Nationalized firms in France participate in research and development activities via the grands programmes. French nationalized firms represent one of the principal components in most of the large scale research and development undertakings implemented by the French government. The importance of this effort has grown as the number of nationalized firms has increased in France.

Six of the largest advanced technology firms in France were nationalized by the Mitterrand government shortly after the Socialists gained power in 1982 -- namely, Thomson, Rhone-Poulenc, CII-Honeywell-Bull, Saint-Gobain, Compagnie General d'Electricite (CGE) and Pechiney-Ugine-Kihlmann (PUK). Other advanced technology industries in France, like telecommunications and the public utilities, have been nationalized for a long time. Further, a large number of advanced technology firms in France are semi-public -- that is, the French government has significant

shareholdings, and therefore has certain control over the management, including participation in research and development efforts (Kindleberger, 1964; Friedman, 1983).

The National Agency for the Valorization of Research (ANVAR) is another French government office which provides private industry with low-interest loans, grants and tax incentives for scientific, research and development activities and for the adoption of advanced technologies. In 1981, about 1500 French firms received ANVAR assistance while by 1988, the number had increased to about 6000.

French private firm expenditures for research and development increased by about 5.3 percent per annum during the 1970s; the increase from 1981 to 1988 was approximately 8 percent per annum.

The French Industry Association or "Patronat" has fully supported the French government's management of research activities. A number of shortcomings concerning the French science research and development activities, as presented above, have been noted.

Since the decision makers with regard to research and development activities in France are civil servants and not industry executives, the decisions are based on administrative considerations formulated by the French government. It is,

however, the market analyses as formulated by industry executives which usually determine the choices, timing, allocation and selection of research and development activities. It has been alleged that without market analyses by industry, that is without the determination of entities willing and able to purchase advanced technology goods, the production of such goods would be a futile activity because the demand for such products may not exist. It has also been reported that the dichotomy of the French industrial sector comprising a few large and technologically advanced firms and many small and backwards enterprises, suggests that this may well not provide a domestic market of sufficient size to warrant the production of advanced technology products with attributes as specified by French civil servants (Balassa, 1985; Hatzichronoglou, 1986).

Finally, the paucity or absence of technological sophistication in the smaller French private sector firms is partly the result of the passive role allocated these firms by French science and technology policies. Unless policies are implemented by the French government which will allow these numerous but small enterprises in France to participate in technology activities, it is likely that France will continue to be plagued by the absence of a sufficiently large demand for advanced technology products. This in turn may retard the entire French science and technology advancement (Crafts, 1984).

8.3 HISTORIC PERSPECTIVE ON FRENCH SCIENCE, TECHNOLOGY, AND INDUSTRY POLICIES

Science and technology policies in France in the post World War II period have passed through a number of phases. Immediately after the end of World War II, the need for the recovery and redevelopment of the French industrial base resulted in formal government policies coordinated with the Marshall Plan (O'Brien and Keyder, 1978). These French government policies were almost exclusively focused on the need to rebuild French industrial facilities and the infrastructure with very limited concern devoted to scientific and technology issues.

In 1952, however, the French government initiated the first post-World War II policies exclusively concerned with scientific and technical issues. These policies called for significant government subsidies to improve the research activities of the French science and technology establishment. In 1956, additional science and technology policies were instituted by the French government, again via subsidies, to promote the use of advanced technologies in French industrial plants and to replace advanced technology imports with native production (Crafts, 1984).

In 1958, the French government established the Interdepartmental Scientific and Technical Research Committee (CIRST), assisted by the Scientific and Technical Research Advisory

Committee (CCRST), set up under Decree No. 58-1144. A joint Secretariat, the General Scientific and Research Agency (DGRST), which acts as a review and executive unit for science and technology activities, was established for these two bodies. A post for a Minister responsible for monitoring scientific research and related activities was also established at French cabinet level (Crafts, 1984).

In the 1960's, under the Gaullist government, considerable additional emphasis was placed on scientific and technological activities in France. A strategy of "national champions"--targeted sectors intended to bring prestige as well as trade competitiveness to French industry, was established in 1962 -- a policy similar to the Japanese "target" industries concept (Cameron, 1970). During this period the most comprehensive of the grands programmes, the Plan Calcul, was initiated to provide significant government support to the French microelectronics and computer industries.

The Plan Calcul was initiated as the result of an agreement between the French government and the French computer firm *Companie Internationale pour l'Informatique* (CII). The massive and coordinated effort by the Gaullist government to launch the Plan Calcul was largely a political reaction to several events which had reinforced the widespread perception by the French government of U.S. dominance of European microelectronic and

computer industries. Among these events, prominent were the acquisition of the French computer firm Machines Bull by the U.S. firm General Electric in 1964, and the refusal by the U.S. government to make advanced U.S. computer technology available to the French Atomic Energy Commission in 1966. These and related events provided the Gaullist government with the rationale for the establishment of native microelectronic and computer sectors in France. The Plan Calcul not only called for the establishment of a viable French microelectronic and computer industry, but also envisioned competition with U.S. computer firms in the world's markets (Arcangeli, et al., 1983).

The Plan Calcul required very extensive cooperation within the French government, among the Ministry of Industrial and Scientific Development, the Ministry of Defence, the Delegation for Information Science and others. It required the cooperation and coordination of various French industrial firms, and French government agencies. It demanded major advances in microelectronic technologies by the French scientific establishment or the purchase of these technologies from abroad, principally the U.S. The Plan Calcul was coordinated by an ad hoc body within the office of the Prime Minister and received significant French government funding (Arcangeli, et al., 1983).

The Gaullist government launched a number of other sectoral plans during the mid-1960's including the Computer Plan, the Space

Plan, the Components Plan, the Construction Plan, and others. In the late 1960's, the Gaullists established two new major policies to direct French science and technology and therefore to provide assistance to the French economy. The first of these was the creation of ANVAR in 1967 with the objective of commercializing scientific research. ANVAR was followed in 1969 by an enactment of formal procedures directed by the French government to convert the results of scientific and R&D activities into applied technology.

None of these activities was successful. The Plan Calcul's failure (it was terminated in 1975) in particular represented a significant but typical failure of Gaullist government science and technology policies (Dosi, 1981).

There are several reasons for the Plan's failure, all of which point to several key weaknesses of French science and technology policies. The principal problems centred on the poor coordination between the Plan Calcul and French macroeconomic policies, or to be more specific, the inability of the French government to sell the microelectronic and computer products resulting from Plan Calcul in the French domestic markets. Potential French users of these products consisting of medium and small French firms were either unable or unwilling to purchase the microelectronic components and the computer systems of Plan Calcul. Another reason for the failure of Plan Calcul was the

unwillingness of the French government to obtain critical technology from the U.S. after it was clear that the French scientific establishment could not achieve the required technical advancement (Friedman, 1983; Ellis, 1978).

The failure of Plan Calcul was a considerable setback for Gaullist science and technology policies. This was especially so, because the French government used in Plan Calcul most of the policy instruments at its disposal as well as almost unlimited funding. The instruments used included outright grants by the French government for research, development and engineering; loans and credit on preferential terms to the firms participating in the Plan; the prohibition of imports of competitive microelectronic and computer products; promises of government purchases for computing equipment and a host of other policy instruments. The French government also assigned to the Plan Calcul its best civil servants (Ellis, 1978).

As a result of the poor performance of the Plan Calcul, the French government established in the mid-1970s two new agencies with a mandate to advance French science and technology: Delegates for Industrial Relations (DIR) in 1972, and Regional Agencies for Scientific and Technical Information (ARIST) in 1974. These two agencies performed reasonably well, but were not able to bring French science and technology to a level where French

advanced technology products were able to compete in world markets with Japan or the U.S.

In the area of computers, the French government ceased advocating a "pure" French computer product and in 1976, with the blessing of the French government, CII, the principal French firm in Plan Calcul, merged with the U.S. firm of Honeywell-Bull. This merger marked the end of a "pure" French mainframe computer industry sector. However, the French government continued to "guide" this new French/U.S. computer enterprise throughout the 1970's and 1980's by providing financial assistance and policy guidance (Geryhadze, 1983).

In the late 1970's and the initial years of the 1980's, the French government continued to assert its role in the advancement of French science and technology via a number of initiatives.

- a) Establishment within the Ministry of Industry of an Innovation and Technology Agency (DIT);
- b) Expansion of ANVAR responsibilities in assisting industries innovation.
- c) Publication of "State of Technology" initial report 1979 (under the title of "Premiers Elements Pour un Programme National d'Innovation") of what was to become Le Rapport sur l'Etat de la Technique (Report on the state of technical development), issued annually.
- d) Creation of a new agency INODEV to provide medium-term funding for industrial innovation.

All of these policies originated at the Ministry level of the French government, using procedures which have become known as the "French model".

The OECD (1985) description of the "French model" is as follows:

When confronted with problems deemed of national importance, the French state, whatever the political complexion of the government, tends to respond in very similar ways. The problems giving rise to a particular policy may differ, but state projects to address them have often looked remarkably alike. According to the French model, the government mobilizes substantial resources -- financial, institutional and manpower-- and directs them to accomplish a predefined task. The reasons for this response are not difficult to find, it being the response of elite technocrats operating from within a centralized bureaucracy, able to draw on a state-dominated financial system. It is a classic top-down approach.

One unique aspect of the French model, not shared with other countries but well established in France, is the requirement that advanced technologies and products used by the French are either government developed, or government owned and operated. The OECD (1985) report states the following on this:

Assuring that the most advanced technology is under national control, that it is produced by a French-owned company, has been a prime objective -- perhaps even the central one -- of French policy for industrial technology. This has often proved incompatible with two other objectives: ensuring the widespread diffusion of advanced technology applications, and protecting the competitive position of the producing company.

and

From the 'Plan Calcul' to current component strategies, the priority has been to guarantee a national supplier, albeit often a weak one. Little distinction was made

between needs of advanced science and military applications, the need for national production capacity and actual commercial production and development (OECD, 1985).

This requirement, of course, contradicts the worldwide trend of multinational corporations, cooperative ventures among nations, cross-licensing, off-shore facilities and other developments which have "internationalized" advanced technology sectors.

The top-down policies used by French governments also assume that technology-push, rather than market-pull will diffuse technology throughout the economy or that after an advanced technology is made available in France it will percolate throughout the numerous sectors of the French economy. None of the French science and technology policies of the 1960's, 1970's, and 1980's has addressed market demand issues. Specifically these policies did not consider the economic and management environment in the French industry sectors particularly in the smaller French firms (Macioti, 1986). The French government's science and technology policies assumed that attainment of technological goals would diffuse into industrial innovation. In this regard they were wrong. Conversely, the Japanese who emphasized diffusion of technologies rather than technological goals have been very successful.

8.4 PRESENT FRENCH SCIENCE AND TECHNOLOGY POLICIES

The current phase of French science and technology policies began in 1981 with Mitterrand as President. As before, the French government adjusted, reorganized, and replaced the government departments and agencies responsible for science and technology policies. Article 1 of Decree No. 81-723 of 28th July 1981 established the Ministry of Research and Technology (MRT) and stated that: "The Minister of Research and Technology is empowered to propose and, in conjunction with the other Ministries concerned, to implement government policy in the field of research and technology."

In September 1982, the Ministry of Industry was merged with the MRT to form the Ministry of Research and Industry (MRI). The life span of the MRI was brief and in 1984 when Laurent Fabius was appointed Prime Minister of France, a new Ministry of Research and Technology was formed and is still in existence today.

The initial structure and responsibilities of the new MRT are essentially identical to those of the old: "The Minister of Research and Technology shall propose and implement the government's policy in the field of research and technology. . . . and . . . he may be delegated by the Prime Minister to chair the Interdepartmental Committee on Scientific and Technical Research." In 1985, the structure of the Ministry was somewhat reorganized by

Decrees No. 85-808 and 85-805, but retained its mission and objectives.

In the present structure of the French government the agencies answerable directly to the Minister of the new MRT are: a) the Scientific and Technical Mission; b) the Research and Technology Directorate (DGRT); and c) the Information, Communication and Scientific and Technical Culture Commission ("DIXIT"). The MRT, however, interacts with a series of other directorates in the French government, including the Regional Development and the Industrial and Technological Environment Directorate (DGDREIT), the International Affairs Agency (DAI), the Industrial Strategy and Statistics Research Department (SESSI), the Forward Planning and Assessment Centre (CPE), and the General Administration Directorate (DAG).

Furthermore, the Minister of the MRT is assisted by a Programmes Committee and the Research and Technology Council (CSRT) which was established in November 1982, and replaced the former "Committee of Wise Men" (CCRST) and the Innovation Mission. The CSRT is comprised of representatives of the French scientific and technical community of industry and research, and of the French social and cultural communities and the regions.

Several other French government departments play certain policy roles in science and industry activities, including the

Ministry of Education, the Ministry of National Defence, the Ministry of Economy and Finance and the Ministry of Posts and Telecommunications.

The French Parliament approves the science and technology budget as recommended by the President. Approval of the budget however is not a pro forma activity and the approval process includes analyses of the goals and objectives of the budget. For this purpose in 1983, Parliament established a "Scientific and Technological Options Assessment Board" to conduct an annual investigation and analysis of the science, technology and industry activities for which public monies are requested.

The current French government apparatus for science, technology and industry policies remains exceedingly complex with an excessive number of separate departments and agencies involved in policy making activities. The implementation of science, technology, or industry policies in France requires considerable and time consuming coordination, hindered by the fact that each of French departments and agencies has its own science and technology agenda, often with conflicting demands (Mitterrand, 1982).

There are other features of the French policy making apparatus which create problems in the execution of science and technology policies in France. One of these is the exclusion of labour, academia and interest groups from participation in the

policy making process and no attempt is made to reach a consensus among these components of the French population. As noted above, CSRT membership includes some representatives from the scientific community with 20 out of 40 members appointed by scientific research organizations and industry, but in practice these members are for the most part civil servants and their influence is minimal. Labour and public interest groups have no representation in the French policy making process (Friedman, 1983).

Another feature which negatively impacts on government policy making in France is the narrow view held by many French government officials, which emphasizes the interests of their department, agency or geographic region over national interests. Several key French technology and industry policies can be traced directly to this emphasis on self-interest. For example the extensive trade barriers which protected certain French industry sectors can be traced directly to the certain local interests in France which protect certain geographic areas (i.e., steelmaking regions) against competition (Northcott and Rogers, 1985). The non-tariff barriers to international trade can also be readily traced to regional or industrial interests in France, as these are directed, not by regional or industry representatives, but by French civil servants whose jobs are related to the affairs of the regions or industries (Dunning, 1977).

Regional and self-interest considerations have also been the principal reason for the extensive French industrial policies which protect and promote declining industry sectors. The comprehensive French government policies enacted at regular intervals throughout the last three decades which have supported steelmaking and shipbuilding sectors in France are examples of this.

The legal and administrative basis for post-1981 science and technology policies in France is the Policy and Planning Act which became law on 15 July 1982. It has two parts:

The first part increases the French science, technology and research effort from 1.8 to 2.5 percent of the GNP, and categorizes in some detail French science and technology activities for funding purposes.

In place of the traditional "interdepartmental block grant," the new "non-defence research and technological development budget" (BCRD) identifies four kinds of science and technology activities:

- a) Fundamental research;
- b) Applied and goal-oriented research;
- c) Technological development programmes;
- d) Multi-year resource mobilizing programmes which involve a), b) and c).

The Act prescribes government policies for each of these four activities.

The second part of the Act sets out the five major French science and technology policy thrusts:

- a) Development and improvement of French national research programme by:
 - i Creating assessment bodies;
 - ii Promoting a "research innovative and creative spirit";
 - iii Strengthening fundamental research; and
 - iv Increasing scientific and technical co-operation, especially in Europe.
- b) Involvement of French regional resources in the national research effort.
- c) Adoption of provisions contributing to the solution of a number of administrative, personnel and related problems in French government research programmes.
- d) Adoption of provisions to encourage and facilitate training for and through research.
- e) Development of guidelines to allow the adoption of regulations concerning the various categories of research personnel recognized as "contributing to the national interest."

The provisions and specifications of the Policy and Planning Act provided the legal and administrative basis for France's Ninth Plan for economic development.

Two additional French laws, both enacted in 1983, provided further guidelines for the most recent French science and technology policies.

The National Plan Law of 13 July 1983, listed ten "Major Actions," of importance including Major action No. 4 ("the scientific, technical and industrial imperative") which formulated broad objectives for scientific, research and development activities.

The National Plan Law of 24 December 1983, defined twelve priority programmes (PPEs), for science and technology activities in France. This Plan Law also prescribed the purpose and scope of contracts between the French government and the French regions and between the French government and public enterprises.

Of these twelve PPEs, seven included research and development as components. The third PPE on "promoting research and innovation" was exclusively concerned with research and development with the purpose of introducing advanced technologies and innovation into French industry, and itemized four objectives of the French research and development effort:

- a) Increase the research and development effort and promote the use of new technologies in enterprises, particularly in small and medium enterprises (SMEs);
- b) Develop staff training in new technologies;

- c) Undertake major efforts at promoting scientific and technical culture and information;
- d) Provide the regions and local authorities with more responsibility.

The "new" element in these recent French policies to advance science and technology is the emphasis for the first time on French regions as active participants in French science and technology activities. However, as reported by several scholars, the driving force behind the inclusion of the regions in French science and technology policies was based on political considerations and not on the obvious need to de-centralize science and technology policies in France.

In order to implement these recent science and technology policies, the French government has established complex funding arrangements by which public monies are provided to the French science and technology establishment.

This system is indeed complex and bureaucratic. The principal decisions for the funding of science and technology activities in France are made by the Ministry of Economics and Finance (Ministere de l'Economie et de Finances) and by the Treasury (Direction du Tresor).

More often than not there are sharp policy disagreements between these two French Ministries, because each has its own

funding plans, priorities, and schedules. Furthermore, both of these Ministries in executing the funding must coordinate their funding functions with four other French government agencies:

(a) The Fonds de Developement Economique et Social (FDES), (the Fund for Economic and Social Development). Created in 1955, the FDES receives budgetary appropriations from the Treasury, and provides low-interest loans to industry.

(b) The Comite Interministeriel pour l'Amenagement des Structures Industrielles (CIASI) (Inter-Ministerial Committee for Industrial Structural Adjustment). Created in 1974 and chaired by the Ministry of Economics, the CIASI is responsible for providing funding to industrial firms which merit the government's concern on policy grounds but are financially weak. Subsidies for such firms are provided from the Fonds d'Intervention pour l'Amenagement du Territoire (FIAT), (Fund for Assistance in Territorial Management).

(c) The Fonds Special d'Adaptation Industrielle (FSAI), (Special Fund for Industrial Adjustment). Created in 1978, the FSAI has the responsibility of assisting French industry in international competition. It also provides financial support to French industrial firms located in regions of France where there is unemployment.

(d) The Institut de Developement Industriel (IDI), (the Institute for Industrial Development). The IDI's objective is to increase the capital equity of middle-sized French firms. The IDI buys shares, lends funds and plays the role of "partner" with some leading firms in their specialized markets.

Recent government policies for science and technology also include a host of regulations concerning financial assistance for advanced technology exports and foreign investment in France.

8.4.1 Financial Assistance for Exports

The French government policies for financial assistance for advanced technology product exports are complex, with more than sixteen types of specific programmes in force in 1989. Export assistance programmes which are currently utilized to a considerable extent by French firms, include financial assistance for investment in production facilities linked to exports, and special loan procedures for exports.

Financial assistance for export-linked investment in France includes, government loans to finance investments designed to promote exports; increased shares of a firm's capital held by the Comite Interministerial de Developement Investment et de Soutien d'Emploi, (CIDISE) (Interministerial Development Committee for Investment and Support of Employment); and subsidies for

investments made to manufacture products to meet the requirements of foreign markets.

The Banque Francaise du Commerce Exterieur (BFCE), (the French Bank for Foreign Trade) created in 1946, provides loans to facilitate exports of French products, with recent emphasis on advanced technology products. It also provides technical assistance to French exporters. Several types of loans are offered by the BFCE: pre-financing loans, the refinancing of loans to enable French exporters to offer short-term credits, and mid-term and long-term loans, allocated by the Banque de France through the BFCE and Compagnie Francaise d' Assurance pour le Commerce Exterieur (COFACE) (the French Insurance Company for Foreign Trade).

8.4.2 Regulations of Foreign Investment

The recent French government policies on foreign investment have continued to emphasize the acquisition of foreign technology, and the close regulation of foreign investment in France. Joint ventures with French partners, particularly those involving advanced technologies or research and development activities are encouraged by the French government.

In the case of joint ventures in industry sectors which the French government considers important for strategic or political

reasons, they are permitted providing control remains in French hands. In order to assure this, the French government "appoints" to the French "side" of a joint venture one or several French civil servants to oversee the administration and management of the joint venture. To limit the foreign control of French firms while assuring access to foreign technology, the French government either restructures foreign firms operating in France or arranges the so-called "French solution", in which French shareholders or the French government purchases sufficient shares of a firm operating in France to control its management.

In spite of these restrictive policies, a large number of foreign entities have begun operations on French soil. There are two reasons why France is attractive to foreign enterprises despite the French government's policies. The fact that France constitutes a significant market for advanced technology products, especially those products which are encouraged by the French government to be developed within the numerous grands programmes, is one reason (Macioti, 1986).

Another reason is the access from France to the markets of the European Community. French government policies to encourage exports add significantly to the attractiveness of France as a base for sales to the nations of the European Community (EEC, 1986; Dunning, 1977).

8.5 GOVERNMENT SUPPORT FOR ADVANCED TECHNOLOGIES IN FRANCE

The French government's policies in support of advanced technology sectors closely reflect its general involvement in French industrial sectors. The French government, has attempted to encourage advanced technology sectors in France by planning and implementing ambitious development programmes, providing funding, arranging mergers of firms, managing exports and imports, setting prices, standards and undertaking a host of other policies.

8.5.1 Microelectronics Sector

Two firms dominated the French microelectronic sector, during the early post-World War II period, Machine Bull and CII. In the 1960s and 1970s, French government policies for the microelectronic industry in France were focused on these two native establishments. The first of the grands programmes the Plan Calcul was directed at the French microelectronic sector. During the period 1966 to 1976, the French government allocated \$350 million to these two firms in an attempt to develop a native French microelectronic industry. The French government also established in 1969 an independent research institute (IRIA) devoted to the advancement of the French microelectronics sector. As described in the previous section, these policies were failures. Machine Bull was purchased in 1967 by the U.S. firm General Electric with the approval of the French government, and

three years later the Machine Bull enterprise was sold to Honeywell, another U.S. firm, which established the Honeywell-Bull Corporation in France. After it had become obvious that Plan Calcul was not a success, the French government attempted to arrange a series of joint ventures for CII with several other European firms in order to form a basis for a joint European computer industry (UNIDATA) managed by the French government. The French government did not succeed in this effort and in 1975, forced a merger between CII and Honeywell-Bull. The new French microelectronic company, CII-HB (with a majority shareholding by the French government), was established at an estimated cost of \$700 million to the French government.

During the same period, the French government attempted to advance French manufacturers of other type microelectronic equipment via another of the grands programmes. The 'Plan Peri-informatique', implemented by the French government in 1967, encouraged the reorganization of the French microelectronic industry around two 'poles,' each a part of the two other major French microelectronics manufacturers, CGE and Thomson-CSF. In order to facilitate "Plan Peri-informatique", the French government forced the sale of two foreign-owned microelectronic component manufacturing subsidiaries operating in France, ITT and Ericsson-France to Thomson-CSF. These other French policies did not result in the expected improvement, and in 1978, in order to

advance the microelectronic industry, the French government undertook the following actions:

- a) Creation of a new research centre-CNET, specializing in the development of new microelectronic products.
- b) Extension of financial support to enable Thomson-CSF and the CEA to develop a Very High Scale Integration programme.

These French government actions were complemented starting in 1978 by a concentrated programme of education and research in microelectronics technology and applications by universities, polytechnics, the CNRS, etc. The expected results of these actions did not materialize (Arcangeli, et al., 1983).

In 1979, the French government established another four industrial consortia for the development and manufacture of microelectronic products.

- a) Thomson-CSF/SESCOSEM which focused on the development of integrated circuits.

- b) RTC (the French subsidiary of the Philips group) which concentrated on high speed bipolar ICs.

- c) EFCIS, (an establishment owned jointly by Thomson-CSF and CEA) which was to manufacture custom NMOS, SOS and CMOS products.

d) Saint-Gobain Pont/National Semiconductor which focused on the development of integrated circuits, with the French government providing some \$443 million in funding.

The stated objectives of these four industrial consortia were indeed ambitious. With these policies the French government attempted no less than the development of French technology to the level of parity with, or superiority to, the U.S. in microelectronics.

In spite of these ambitious policies the French native microelectronics industry sector remained weak. The expected technological advances did not take place, French exports of microelectronic products were essentially nil and U.S. exports of microelectronic products to France increased significantly.

In 1982 France's new Socialist government nationalized the French microelectronics industry and took over the principal French microelectronics firms -- Bull, Thomson-CSF, and Compagnie Generale des Constructions Telephoniques. Nationalization of these firms was immediately followed by a series of very large French government grants to the nationalized microelectronics sector. During the 1982 to 1988 period, the French government provided grants to the native microelectronics industry estimated at \$14 billion.

The new socialist government also established another new centre for microelectronic research in France. The Filiere Electronique was initiated in the spring of 1982 as a five year effort with public and private investments over the 1982 to 1988 period of \$32 billion. The stated goals of Filiere Electronique in 1982 were to:

- a) increase the production of microelectronic products by 3 to 9 percent per annum;
- b) create a surplus trade balance in micro-electronic products; and
- c) generate 80,000 new jobs per year (SAI, 1985).

The table below provides a summary of proposed funding for the 1982 to 1986 period.

	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>
Total Government	4.0	6.7	7.6	8.0	9.2
Funding (FF billions)					

Source: Ministere de l'Industrie et de la Recherche,
"La Politique Industrielle de la Filiere
Electronique," November 1983.

Most of the support was obtained from the Ministry of Defence, followed by the Telecommunications and Industry Ministries. The role of the Ministry of Defence was cardinal in the selection, direction and coordination of the Filiere activities. Table 8.4 provides an overview of the industry structure which emerged at the end of 1983, after the French government's

TABLE 8.4

Government Directed Company Specialization
of the French Microelectronics
Industry, 1983

<u>Field</u>	<u>Leader</u>
Components	Thomson Matra-Harris
Consumer Electronics	Thomson
Professional Electronics	Thomson
Telecommunications	CGE (CIT-Alcatel)
Computers	Bull
Office Equipment	Bull

Source: SHC, 1985.

nationalization policies of the microelectronics sector had been implemented.

The research emphasis at Filiere Electroniques prescribed by the French government was concentrated on six projects:

- a) large scientific and industrial computers
- b) computer-aided design, engineering, and production
- c) computer-aided design for VLSI
- d) display
- e) computer-assisted instruction
- f) computer-aided translation.

Filiere Electronique was also directed to link French government research centres with French microelectronics industry sectors.

Under the Mitterand policies regarding the microelectronics sector in France, Thomson and Matra-Harris were the firms designated to provide the core thrust to the French native microelectronic industry. International cooperation in microelectronics was the responsibility of Filiere. This structure of the French microelectronic industry established in 1983 remains essentially in force in 1989.

During the 1982 to 1988 period, the French government also negotiated a number of cooperative technology agreements between nationalized French microelectronics enterprises and foreign firms. In 1984, an agreement was concluded to share technology

between Bull and Convergent Technologies and Ridge Computers, both from California USA. Compagnie Generale d'Electricite in 1985 concluded an agreement for joint production with the U.S. firm Intel. In 1985, Thomson acquired Mostek, a major microelectronics firm in the U.S. In 1985, Thomson also arranged for technology exchanges with the Japanese Oki Electronic and Motorola in the U.S., and in 1987 Thomson merged its microelectronics operations with the state-controlled Italian microelectronic firm S.G.S.

These changes resulted in only marginal improvements in the French performance in the microelectronics world market and in 1987, France accounted for less than one percent of the world's microelectronic product output.

8.5.2 French Policies to Advance the Machine Tools Industry

The history of the French machine tool industry also indicates significant French government involvement in this sector of the French economy. The indigenous machine tool industry in France has always operated under the shadow of the excellence of its German neighbour, although the French government has long been determined to create a strong domestic machine tool sector. The machine tool sector ranked as a high priority sector in the French industrial policies of the 1950s with preferential allocations of steel and skilled manpower at a time when both were in very short supply. In the 1960s, the French machine tool industry improved

in terms of output and technological advancement as a result of French automobile manufacturers' involvement with Renault and Peugeot providing assistance to French machine tool makers in the 1960's. The French machine tool industry, however, could not compete with the technological advances made in Germany and the U.S. and went into a decline in the early 1970's, remaining marginal throughout the 1970's (Rendeiro, 1984).

The socialist government under Mitterand in 1981 established a comprehensive national machine tool plan which in effect created two large nationalized groups of firms or 'pole de developement.' Both involved extensive horizontal mergers among the existing French machine tool makers.

The Machine Francaises Lourdes (MFL) group became France's producer of heavy-duty machine tools, concentrating on the whole on the traditional, one-off heavy-duty machine tools.

The other major 'pole de developement' for the industry was Interlautomatisme, encompassing Hure (specialized milling machinery), Graffenstraden (horizontal machining and flexible manufacturing systems) and H. Ernault Somua (lathes).

In late 1981, the French Council of Ministers adopted a three-year restructuring and development plan for the French machine tool industry. The major goals of the plan were to (a)

foster concentration of the French machine tool industry on the needs of advanced technology sectors; (b) regroup and refinance machine tool firms in order to create larger, more specialized and more competitive companies; and (c) reduce the growing dependence of French manufacturing on foreign imports of numerically controlled machine tools (EEC, 1986; ITC, 1986).

The specific objectives of the plan's implementation programme were to (a) double total French machine tool production by 1985 and in so doing, quadruple production of numerically controlled machine tools; (b) increase 5-fold R&D expenditures; and (c) reduce by one-half the foreign share of the French market, (i.e., to a range of 30 to 35 percent) and double French machine tool exports to industrialized countries. The programme undertaken by the French government, under the sponsorship of the Ministry of Industry, provided for direct financial assistance for machine tool manufacturing consolidation and development, support for manufacturing research and development, and increased public procurement (EEC, 1986).

The level of government funding allocated at the end of 1985 for the implementation of the plan's 3-year programme was approximately \$682 million which was to be matched by funding of about \$461 million from French companies in the machine tool industry and from private-sector sources. Under this programme, French machine tool purchasers (users) could receive financial aid for

the acquisition of automated machine tools and, subsequently, government-backed loans at preferential interest rates for the purchase of additional machines.

The U.S. National Academy of Sciences (NAS) characterizes the French government policies in the machine tool sector in this period as follows:

The French government formally classifies companies into industrial categories. The approximately 250 companies classified as machine tool builders have levied upon them a special tax earmarked for technical research at an R&D institute in Paris, Comite European de Cooperation des Industries de la Machine Outil (CERMO). With a full-time staff of approximately 30, CERMO conducts research in manufacturing engineering in areas of particular relevance to machine tools. Located within a technical school, CERMO is also a training center and offers an engineering degree. Apart from its role in research and training, the French government is also active in promoting the diffusion of new machine tool technology. In 1980 it distributed about \$4.3 million to small French companies to aid them in the purchase of NC machine tools. In 1981 the French government announced a major aid plan for the machine tool industry, involving more than \$400 million in direct grants over a 3-year period, and a restructuring of the industry around major product categories. In 1986 another grant of \$600 million was announced (NAS, 1986).

The French Ninth Plan for industrial development called for a priority effort aimed at the modernization of French industry and provided additional assistance to French machine tool makers. The Plan stated that to remain competitive and improve their market shares, French enterprises must embark on a decisive technological phase requiring the installation of automated manufacturing facil-

ities such as numerically controlled machines, robots, industrial data processing and automated materials handling machinery. In order to accomplish these goals, the French government allocated for research about \$400 million in 1984 and a total of \$2.4 billion over the five year life of the Ninth Plan.

French government policies for the development of industrial robots began in 1981, when the First Plan, known as "Filiere Robitique," was established by the French Government. The objectives of this Plan were increased research and development effort in robotics, automation, mechanics, electronics, hydraulics and software, as well as the diffusion of automation technologies. The 1981 budget for the Plan was over \$46 million, and similar plans have been established every year since 1982 at an average annual budget of \$55 million.

To increase the level of automation in industrial sectors, the French government in 1982 began to encourage foreign robot producers to invest in French firms. The Robotics Mission of the French Ministry of Research and Technology had budgeted \$350 million during the 1983 to 1987 period to create an Inter-Agency Robotics Committee. The objectives of this Committee consisted of funding the research and development of robotics, training robotics specialists, and extending low-cost financing to potential robot users.

Over \$1.6 billion was initially earmarked for funding robot-related projects in France during the 1982-87 period. However, by mid-1983, economic difficulties forced the French government to reduce its planned yearly funding, and the actual funding for robot-related projects over the 1982 to 1987 period was about \$400 million. Table 8.5 summarizes the key research areas in robotics undertaken as part of government policies in this sector.

As a result of these French government policies, the French machine tool sector increased its production by some 15 percent in the late 1970's. However, French machine tool makers could not compete with the very substantial technological advancements made in the machine tool industry by the Japanese nor could it compete with the Japanese in terms of prices.

Furthermore, the German machine tool industry, historically a very strong international competitor, increased its exports to France in the 1980's. As a result of this competition the French machine tool sector in the mid-1980's had to reduce its sales in France, and significantly curtail its already marginal presence in the world's markets for machine tools.

8.5.3 French Government Policies in the Advanced Materials Sector

The French government has undertaken very marginal attempts to establish an advanced materials industry in France. Allegedly,

TABLE 8.5
Robotics Research in France by Institution and
Focused Area of Research, 1988

<u>INSTITUTION</u> <u>Universities</u>	<u>FOCUSED AREA OF RESEARCH</u>
Technical University of Compiègne	Real time vision processing, geometric data-base design, systems integration
University of Lille	Basic research issues
<u>Government In-House Laboratories</u>	
LIMSI	Manipulation of assembly, visual inspection, work cell integration
INRIA	Perception: Laser illumination for assembly & inspection, 3-D vision, obstacle avoidance
LAAS	Sensors and sensor data proces- sing, systems integration: control for assembly, perception, planning ARA Project, mobile robot
IMAG	Robot programming tools (developed language LM) automatic assembly, expert manufacturing planning, vision: gray scale & 3-D using laser
CGA	Inspection of nuclear facilities
LAM	Modelling and control of manipula- tors, simple vision, coordination of multiple robots
DERA	Control systems; flexible automation and robots for space systems
National Robotics Lab.	Various applied research issues
<u>Industry Laboratories</u>	
Renault	Industrial robot research vision for inspection, controllers, process planning
MATRA	Fast vision module; Assembly robots
Source: SHC, 1985	

the French Ministry of Defence has funded research on advanced materials from several nationalized industries and the CNRS, but the details of this funding are not available. None of the French chemical, automotive, or machinery firms is engaged in the research and development of advanced materials.

8.6 CONCLUSIONS

French government policies to encourage the advanced technology sector development in France have resulted, at best, in marginal technological and market improvements. France certainly has lost its competitiveness in world-wide markets for advanced technology products. A number of reasons may be suggested for this failure.

The dual state of the French economy, consisting of a relatively small number of technologically very advanced firms controlled by the French government and a very large number of firms which can be accurately described as backward is one of the reasons for this failure. The French emphasis on the supply side (or the producer) of advanced technology products comprised, for the most part, of large government-controlled firms at the expense of the demand side consisting of numerous small and medium sized entities is another. The very low rate of diffusion of advanced technology products within French industrial sectors, particularly among the smaller enterprises, and the French

government's unwillingness to correct this is another reason for the poor performance of French advanced technology sectors.

The traditional French solutions to the problems facing the French economy, grands programmes undertaken by government controlled firms, may not have been the most appropriate to improve advanced technology sectors in France. Other reasons for the French failure is the unwillingness of the French government to explicitly consider the needs of the smaller and medium sized firms, to seek policy consensus with these firms, and to appreciate the awesome international competition in advanced technology sectors from the U.S. Japan and some other nations.

CHAPTER 9:

SCIENCE, TECHNOLOGY AND INDUSTRY
POLICIES IN GERMANY

9.1 INTRODUCTION

The German economy has performed well in the postwar period, with some notable achievements in science, technology and industrial advancement. In 1988, Germany's GNP was estimated at \$691 billion, an increase of over 40 percent in the last two decades. Germany's trade balance in 1988 was a positive \$130 billion, as compared to \$80 billion in 1975. Germany's exports of all manufactured products have gradually increased throughout the entire post-World War II period. In 1955, Germany's exports of manufactured products represented 14.6 percent of total world exports; by 1987 this percentage had increased to 18.3 percent. In 1955, Germany exported 17.6 percent of total advanced technology product exports in the world; by 1987 this percentage had increased to 24.3 percent.

Germany has relied on a macroeconomic policy emphasizing price stability and most important, export-led growth. The role of government policies in promoting science and technology has been very limited. For the most part, science and technology activities and industrial growth and development in Germany, have been left to market forces. Some debate about the need for science and technology policies to promote advanced technology

industries, the so-called "Strukterpolitik", was initiated in Germany in the mid-1980's principally by members of German academia (Gremmen and Vallenbergh, 1986). The sharp reduction of German machine tool exports, an industry where Germany has been historically dominant, prompted this debate. Free market forces prevailed with the support of industry groups such as the Federation of Germany Industry (BDI); explicit government intervention in the German market economy was rejected. The German government continues to direct the country's economic growth with broad macroeconomic policies, and some support for German science, research and development activities (Daly, et al., 1985).

9.2 INSTITUTIONAL SETTING IN GERMANY

Four German institutions, the Council of Economic Advisors, the Ministries of Finance and Economics, and the Deutsche Bundesbank, plan and execute German macroeconomic policies in close cooperation with German industry and labour unions. The four principal German policy making institutions cooperate closely with the Ministry of Research and Technology (BMFT) which guides science and technology activities in research institutions, universities and industrial firms and with Ministry of Economics, the principal German agency for industrial development.

Established in 1972, the BMFT has developed a variety of programmes to assist Germany's science, technology and research and development activities as well as industrial sectors. The BMFT provides most of the funding for the Fraunhofer Gesellschaft, a nonprofit society that conducts a very significant portion of applied research and development in Germany and provides support to such major German research organizations as the VDI Technology Centre. The Fraunhofer Gesellschaft (Society) comprises 28 individual research institutes, each with its own facilities, personnel, and research programme. The institutes are organized on a disciplinary basis and each institute has an independent board of directors with strong industry and academia representation. The BMFT also provides significant support to various German trade associations.

The German Ministry of Economics, the principal German government agency for industrial development, supports some eighty German industrial research associations, organized across disciplines to cover the range of technologies important to a particular industry sector.

Science, technology, and research and development activities supported by the Ministry of Economics and the BMFT, place considerable emphasis on the development of industry products which are designed for export markets. The emphasis on exports is however not dictated by German government policies, but results

from the historical export market orientation of German industry and labour (Kriele, 1978).

The involvement of labour in the management of German industrial firms is strong. Labour union representation in the BMFT and Ministry of Economics is substantial and labour participation on the supervisory boards of German corporations is required by law.

The involvement and concern of German labour unions about the development of German industry, export potential and international competitiveness is a unique characteristic among industrialized nations. Equally unique is the labour union representation in the management functions of German industrial firms (Bulmer, 1983).

9.3 SCIENCE, RESEARCH AND TECHNOLOGY RESOURCES IN GERMANY

The organization and support of scientific, research, technology and industry activities in Germany is diverse and complex. Germany's science and technology activities are undertaken at both the German federal and state (Laender) levels, with policy advice provided by numerous German science advisory bodies.

The current German research and technology activities are guided by the four principles promulgated by the German government (BMFT) in 1983:

- a) Need for freedom of academic research;
- b) Restraint by the government in interfering with research carried out by industry;
- c) Reaffirmation of technological progress as necessary to international competitiveness, economic growth and full employment;
- d) Recognition of performance as a stimulant to productivity in R&D.

The resources for science and technology activities in Germany which strictly adhere to these four principles consist of higher education institutions, German government laboratories, and industry.

9.3.1 Higher Education Institutions

The universities in Germany represent a significant force in scientific, research and development activities. Essentially all universities are state institutions, but are by law independent bodies that are free from most German government regulations. There are four types of higher educational establishments in Germany; comprehensive universities, technical colleges, colleges of education, and polytechnics. The latter two provide three-year courses of study while the comprehensive universities and technical colleges provide four- to five-year baccalaureates as

well as advanced study programmes. In 1987, there were sixty-three comprehensive universities and technical colleges in Germany. These performed essentially all of the research and development activities of the German higher education institutions. Research activities in German colleges of education and polytechnics are of minor importance.

The German Laender, or state governments, provide the principal funding for all German comprehensive universities and technical colleges. In 1987, about 83 percent of total research and development expenditures in the universities was financed by the Laender. Another 15 percent was financed by the German government, and less than 2 percent by industry (Table 9.1).

9.3.2 German Government Research Establishments

Research establishments administrated by the German federal and Laender governments undertake most of the applied research and development activities in Germany. These establishments also accounted for about 26 percent of basic research activity in Germany in 1987. The research organizations comprise three broad categories: a) research institutes subordinate to the Max Planck Society, the Fraunhofer Society and other independent coordinating organizations which receive all or substantial portions of their support from the German federal and state governments; b) German national laboratories supported largely by the Ministry for

TABLE 9.1

Breakdown of University Expenditures on
Research and Development, by Source:
Germany, 1987

	<u>Percent</u>
Government	98.5
Federal	15.4
Laender and Local	83.1
Industry	1.5
Other Sources	--
TOTAL	100.0

Source: Federal Ministry for Research and Technology,
Bundesbericht Forschung, 1988

Research and Technology; and c) individual research establishments subordinate to the various German Federal and Laender Ministries.

9.3.2.1 Research Institutions Subordinate to Independent Coordinating Organizations

Organizations included within this category are the research institutes of the Max Planck Society, the Fraunhofer Society, and a number of German academies of science. The most important of these organizations are the institutes within the Max Planck Society (Table 9.2).

The Max Planck Society for the Promotion of the Sciences, Max-Planck-Gesellschaft zur Foerderung der Wissenschaften -- (MPG) is the largest and most prestigious of all German research establishments. Established in 1948 as the successor to the pre-war Kaiser Wilhelm Society, the MPG undertakes scientific and research activities which cannot be undertaken in the German universities, such as large interdisciplinary research projects or research requiring specialist equipment or facilities. Table 9-3 provides information on the distribution of activities by field of research at the Max Planck Society.

There are a total of 68 research centres managed by the Max Planck Society. Most of these are located near major German comprehensive universities or technical colleges in order to share scientific personnel with the academic institutions. These

TABLE 9.2

List of Institutes of the Max Planck Society, Germany

MPI for Aeronomy
MPI for Astronomy
MPI for Chemistry
MPI for Biophysical Chemistry
MPI for Ferro-Research
MPI for Solid State Research
Fritz-Haber Institute for Physical Chemistry
Gmelin Institute for Inorganic Chemistry
MPI for Nuclear Physics
MPI for Coal Research
MPI for Mathematics
MPI for Metal Research
MPI for Meteorology
MPI for Physics and Astrophysics
MPI for Plasmaphysics
MPI for Polymer Research
MPI for Quantum Optics
MPI for Radio-Astronomy
MPI for Radiation Chemistry
MPI for Fluid Dynamics Research
MPI for Biochemistry
MPI for Biology
MPI for Biophysics
MPI for Experimental Endocrinology
MPI for Nutritional Physiology
MPI for Medical Research
MPI for Neurological Research
MPI for Physiological and Clinical Research
Friedrich Miescher Laboratory for Biological Research
MPI for Molecular Genetics
MPI for Brain Research
MPI for Immune Biology
Clinical Research Groups of the University Clinics of Goettingen
Clinical Research Group for Blood Clots and Thrombosis
Clinical Research Group for Reproductive Medicine
MPI for Biological Cybernetics
MPI for Limnology
Research Laboratory Matthaei
MPI for Experimental Medicine
MPI for Psychiatry
MPI for Psycho-Linguistics
Research Laboratory for Psychopathology
MPI for Systems Physiology
MPI for Behavioural Physiology

TABLE 9.2 (Continued)

MPI for Virus Research
MPI for Cell Biology
MPI for Plant Breeding Research
Bibliotheka Hertziana (of Italian Art, Rome, Italy)
MPI for Educational Research
MPI for Psychological Research
MPI for History
MPI for Patent Law
MPI for Foreign and International Private Law
MPI for International Law
MPI for European History of Law
MPI for Social Law
MPI for Social Sciences (is being disbanded)
MPI for Criminal Law

Source: Federal Ministry for Research and Technology,
Bundesbericht Forschung 1988.

TABLE 9.3

Allocation of Research Funding
Within the Max Planck Society,
By Field of Research, 1987 Budget

<u>Field of Research</u>	<u>Percent</u>
Astronomy & Astrophysics	7.6
Chemistry	12.2
Physics I	10.0
Physics II	25.3
Mathematics (Informatics)	1.7
Meteorology, Aeronomy and Space Research	6.9
Biomedical Research with Primates and Humans	13.7
Psychology and the Biological Aspects of Behavioural Research	3.3
(Plant) Breeding Research and Ecology	2.3
Law	2.6
History	1.4
Social Sciences	2.4
TOTAL	100.0

Source: Federal Ministry for Research and Technology,
Bundesbericht Forschung 1988.

centres vary in size from a few scientists to the larger institutes with scientific and technical personnel in excess of one thousand.

In 1987, the number of scientific and technical personnel working at various Max Planck Society institutes was estimated at 10,000. An additional 2,400 scientists worked at MPG institutes as visiting scholars from other German research organizations and from other countries.

The Fraunhofer Society for the Promotion of Applied Research-- Fraunhofer-Gesellschaft zur Foerderung der Angewandten Forschung -- (FhG) is a German research society which focuses explicitly on applied research. The FhG was founded in 1949 to pursue "... research and development in the fields of the natural sciences and engineering on behalf of industry and government" (Geimer, 1978). In 1987 the FhG comprised 30 separate institutes which carried out contract research in the following areas: production technology, materials sciences; process engineering, energy technology, construction engineering, microelectronics, sensor technology; information technology, production automation, and environmental technology. These FhG institutes are located near comprehensive universities as in the case of MPG institutes, and the technical and research staffs at FhG institutes have appointments also at the universities.

In addition to the MPG and the FhG, so-called German Academies of Sciences also undertake research and development activities but their principal role is the dissemination of scientific and technical information. These organizations are characterized by their triple roles as scholarly societies, agencies for long-term research projects, and publishers of the results of research undertaken in all industrialized nations for the benefit of the German science and technology establishment (Prais, 1981).

9.3.2.2 German Government's National Laboratories

There are a total of thirteen German national laboratories supported primarily by the German Ministry of Research and Technology. The research effort conducted in these laboratories consists of scientific and applied research activities that require special, dedicated and costly apparatus, equipment, and facilities. The National Laboratories are established and funded by the German federal government. However National Laboratories are legally independent institutions organized as private associations, under German laws of "registered association," "limited liability company," or "foundation". German government authority over National Laboratories exists only in the form of very general regulations. Research objectives, are established by each National Laboratory. The thirteen German National Laboratories in 1987 employed over 6,000 scientists, technicians, and engineers.

All of the National Laboratories are linked together under an Association of National Research Centres (AGF), which coordinates their scientific as well as management activities and represents their interests at the federal government level.

9.3.2.3 Research Establishments Subordinate to the German Federal and Laender Ministries

Individual research institutes and other facilities directly subordinate to the German federal and Laender ministries, represent another component of Germany's science and technology resource pool. There are three types of organizations: a) research facilities or institutes directly subordinate to the German Government's federal ministries; b) research facilities or institutions directly subordinate to the Laender; and c) institutes or facilities on the so-called "Blaue Liste" that are jointly financed by the German federal authorities and either single Laender or all of the Laender.

In 1987, there were a total of forty-one research institutes subordinate to the German Federal government ministries, referred to as "federal government research establishments." Most of the research performed in these establishments is in direct support of their ministry's mission. In 1987, these research establishments employed a total of 14,500 personnel.

The Laender operate their own research institutes similar to those of the German federal government, and in 1987, there were 50 such institutes financed by the individual states in which they were located. These institutes undertake both basic and applied research serving the requirements of an individual German state or a particular region of Germany.

There are 46 joint German federal-state research institutes which comprise the so-called "Blaue Liste." Established in 1975 under an agreement between the German federal and Laender governments known as the "Skeleton Agreement on Research Promotion", these institutes undertake principally applied research and development. In 1987 the total scientific and technical staff in these institutes was about 1,400.

9.3.3 Research Facilities Operated by German Industry

Most of German industry's research and development is undertaken by individual German industrial firms, with cooperative research ventures between German firms being limited. The breakdown of German industry's funding for research and development by industry sector is shown in Table 9.4.

TABLE 9.4

German Industry-Financed R&D Expenditures, Germany, 1987

<u>Sector of Industry</u>	<u>Percent R&D Financed by Industry</u>
ENERGY AND WATER SUPPLY, MINING	
Electricity, Gas & Water Supply	81.1
Mining	40.6
Total	50.7
MANUFACTURING	
Chemical Industry, etc.,	
Processing of Mineral Oil	95.2
Chemical Industry	98.0
Manufacture of Plastic and Rubber Products	96.9
Construction Material, Ceramics and Glass	94.7
Production of Metals and Manufacturing of Metal Products	76.2
Iron-Producing Industry	66.3
Steel, Machine and Auto Production, etc.	82.6
Machine Construction	92.8
Manufacture of Autos and Spare Parts	96.1
Aeronautics and Aerospace Vehicle Manufacture	27.6
Electrotechnology, Precision Mechanics, Optics, etc.	86.3
Electrotechnology	86.6
Precision Mechanics and Optics	91.8
Timber, Paper, and Printing Industry	96.8

TABLE 9.4 (Continued)

Leather, Textile and Garment Manufacture	85.1
Food Industry	96.8
Total	87.3
ALL OTHER SECTORS OF INDUSTRY	61.1
 TOTAL	 85.2

Source: Adapted from Federal Ministry for Research and Technology,
Bundesbericht Forschung 1988.

The proportion of German industry's financed research and development activities is increasing. In 1970 German industry funded 53 percent of total German research and development activities and by 1987 this proportion had increased to 65 percent. Industry supported research activities are organized in a total of seventy-nine associations along areas or disciplines of research.

All industry funded research and development activities in Germany are represented by the Confederation of Industrial Research Association (AIF), comprised of the seventy-nine professional member associations.

9.3.4 Conclusions

The German science, technology, research and development establishment has formed close working relationships among the various research organizations in Germany as well as among the German federal and Laender governments' departments and agencies (Deich, 1979).

The numerous institutions of the MPG and the FhG serve as conduits of scientific information to other research establishments in Germany. Essentially all German communities have an active science association, often sponsored by the local industrial establishment. These associations have regular

meetings, presentations and lectures by members of the German science establishment, academia, and German government officials. Information concerning recent developments in science and technology is therefore rapidly disseminated in Germany (Gehrels, 1983).

German research and development personnel are also well trained in their respective science and technical areas. The initial formal training in German academic institutions is supplemented by periodic scientific and technical courses provided in many localities in Germany. The formal training requirements in Germany exceed those of most other industrial nations. Even the support personnel such as factory foremen receive formal instructions. The term "skilled" in Germany (Fahman) is used only after completion of formal training period, whereas in many other industrial nations, the term is applied to individuals with long work experience. These characteristics allow for the rapid diffusion of advanced technologies throughout German industry, and create domestic demand for advanced technology products and services (Gremmen and Vallenbergh, 1986).

The innovative characteristics of German industry can be readily seen from the number of U.S. patents granted to German scientists. In 1987 the U.S. Patent Office granted German scientists a total of 6,900 patents; the corresponding number for

French scientists was 2,100 and for British scientists it was 2,500.

9.4 FUNDING PATTERN FOR SCIENCE AND TECHNOLOGY IN GERMANY

Expenditures for research and development in Germany, by source of funds for the 1978 to 1986 period, are shown in Table 9.5. In 1986, German federal and Laender government sources accounted for 42.3 percent of the total, German industry accounted for 56.2 percent, and less than 2 percent came from other sources such as private foundations and foreign sources. Of the total German government funding, about 60 percent came from federal sources and 40 percent from the Laender governments.

Of the total German federal government research and development funding, the BMFT accounts for about 57 percent, followed by the Ministry of Defence, (16 percent), the Ministry of the Economy (9 percent), and the Ministry for Education and Science (BMBW) (8 percent). The other German federal ministries account for the remaining 10 percent.

The BMFT represents the most important German federal government source of financial support for research in Germany. In addition to financing its own research, the BMFT also provides support to the MPG, the FhG, the National Laboratories, and the German Research Society (DFG). The BMFT budget for 1986 is shown

TABLE 9.5

Gross Expenditure for Research and Development,
by Source: Germany, 1978-1986
(Million DM)

<u>Year</u>	<u>Total</u>	<u>Government</u>	<u>Defence</u>	<u>Space</u>	<u>Industry</u>	<u>Other</u>
1978	31,620	13,770	1,756	566	16,870	980
1980	39,040	17,070	1,704	633	21,050	920
1982	44,570	19,400	1,695	696	24,470	700
1984	46,780	19,780	1,858	762	26,300	700
1986	50,800	19,900	1,900	800	27,400	800

Source: Federal Ministry for Research and Technology,
Bundesbericht Forschung 1987.

in Table 9.6. Of the BMFT's total budget, about half is allocated to project support, another 36 percent to support for research institutions, 10 percent to international organizations and programmes, and the remaining 4 percent to indirect research support and administration.

The BMBW plays a significant role at the federal level in the provision of financial support for research, primarily to the German universities. The BMBW provides most of the German federal Government's contribution to the funding of the DFG.

The DFG is a non-governmental organization, even though its funds are received almost entirely from the German federal and Laender governments, with about 59 percent of funds provided by the German federal government (primarily through the BMBW), and 40 percent from the Laender. Its principal function is to provide funding for research in the German Comprehensive Universities.

Several German private foundations are also important as funding agents for science activities in Germany. Significant among these is the Donors Association for the Promotion of Science and Humanities, supported by German industry for the promotion of science related research and teaching. The Donors Association is supported by approximately 5,000 German industrial enterprises, and has a budget of about forty million DM a year.

TABLE 9.6

German Federal Ministry for Research
and Technology: Budget, 1986

<u>Areas of Special Emphasis</u>	<u>(Million DM)</u>	<u>(Percent)</u>
Basic Research and Programmes Oriented Toward Basic Research	2,385.1	32.9
Max Planck Society	407.8	5.6
Miscellaneous R&D in Natural Sciences	867.8	12.9
Space Research and Technology	816.6	11.2
Marine R&D	164.2	2.3
Polar Research	64.5	8.9
Humanities and Social Science	64.3	8.5
Orientation Programmes	91.7	1.3
Research on Ecological Impacts	66.9	8.9
Climatic Research	28.8	8.3
Technological Assessment, Research Planning	4.9	8.1
Promotion of R&D in Important Areas of Government Forward Planning	2,955.4	48.7
Environmental Technologies, Water Research	157.2	2.2
Fossil and Renewable Energy Sources: Rational Energy Utilization	678.5	9.2
Nuclear Energy	1,638.7	22.6
Health R&D	318.6	4.6
Humanization of Labour	184.8	1.4

TABLE 9.6 (Continued)

Promotion of R&D in Key Technologies	1,160.6	16.8
Information Technologies	671.8	9.1
Materials Research	83.5	1.2
Biotechnology	125.2	1.7
Physical Technologies, Chemical Processing Technologies	189.8	1.5
Aviation R&D	171.9	2.4
Improvement of Basis for Industrial R&D and Promotion of Innovation	338.3	4.5
Fraunhofer Society	114.9	1.6
Improvement of Technology Transfer	58.5	8.8
Support for the Establishment of Technology-Oriented Enterprises; Risk Capital	68.8	9.8
Special Information Systems	96.9	1.3
Promotion of R&D and Innovation in Public Administration	280.5	3.9
Ground Transport and Traffic	186.8	2.6
Geosciences and Raw Materials R&D	24.8	1.2
Safety R&D (as far as not contained in special programme areas)	9.7	8.1
Other (Stipends, Exchanges)	45.2	8.6
Administration	51.1	8.7
TOTAL	7,268.8	100.0

Source: Federal Ministry for Research and Technology
Fact Sheet, 1988.

The other large German private foundation funding research is the Volkswagenwerk Foundation, which provides research grants to German non-profit institutions engaged in research and higher education.

9.5 GOVERNMENT SUPPORT FOR ADVANCED TECHNOLOGIES IN GERMANY

Neither the German federal government nor the Laender have enacted science, technology or industry policies which impact on free market operations in Germany (Hager and Taylor, 1982).

The German federal and Laender governments have funded some research and development for advanced technology sectors as well as supported educational activities and training. Very modest procurement policies have also been enacted by the German federal government.

9.5.1 Support to the German Microelectronics Sector

The German microelectronics industry, with Siemens A.G. as the principal firm, has maintained a modest stake in the world's microelectronic markets for several decades with very limited assistance from the German government. In 1988, the German microelectronic sector had world-wide sales of \$780 million and a 1.8 percent share of world markets. In 1964, Germany's share of the world wide microelectronics market was 1.4 percent. In the

1960's and 1970's, Germany maintained its modest market share by undertaking in-house research and development activities. In the mid-1980's, Germany's microelectronic industry turned to foreign technologies to maintain its microelectronic production at home as well as to continue to export some microelectronic products. Federal government assistance to its native microelectronic industry was limited throughout this period (Northcott and Rogers, 1985). In 1985 Siemens A.G. purchased advanced microelectronic technology from the Japanese Toshiba Corporation and in 1987, Siemens joined forces with the N.V. Philips Corporation from the Netherlands to develop next generation microelectronic devices, i.e. DRAMS, one of the most widely-used microelectronic components.

The initial attempt by the government to assist the German microelectronics industry was in 1967 through training programme support. In 1971, the German federal government established a very modest public procurement policy giving preference to German microelectronic products (El-Agraa, 1985).

Between 1974 and 1978 the BMFT operated a programme of support for the German electronic components industry with research and development funding of about \$30 million per year. In 1979 this support was terminated.

Also in 1978, the BMFT provided funding for research focused on integrated circuits to be used in television and radio sets by German manufacturers. This programme also included support for the development of new microelectronics manufacturing technologies (Drais, 1981).

Clearly German government support for its native microelectronics industry has been modest (Neuman, 1981; Aquino, 1983).

9.5.2 German Policies in the Machine Tools Sector

Governmental support to the German machine tool sector has also been modest and mostly indirect (Hutton, et al., 1977). The government has provided some funding for German institutions engaged in research and development programmes directly focused on production, i.e., process technology, automated manufacturing, and flexible manufacturing systems. For example, the German government has, during the past several decades provided support to the machine tool industry via its annual funding of several research establishments. The Technical Research Institute at Aachen, considered by many to be the best machine tool laboratory in the world, was the principal recipient of funds for research from German federal and Laender governments (Daly and Jones, 1980). The German machine tool industry has also benefited indirectly from governmental tax incentives and other aid programmes available to all German industries to advance production

technologies. Examples include programmes aimed at bringing efficiency to small and medium size firms, promoting "knowledge-intensive" businesses, stimulating research and development, and assisting export-oriented industries (ITC, 1984). Beginning in 1979, many small and medium size German firms, including machine tool companies, were able to receive grants from the Federal Ministry of Economics for personnel improvement in the form of contributions to wages and salaries of research and development personnel (Gehrels, 1983).

Two other sources of indirect financial assistance to the German machine tool industry have been available over the last several decades:

- a) Since 1978, firms with sales of up to \$75 million, have been eligible to receive payments from the BMFT for outside contracted research.
- b) Since 1982, the BMFT has entered into agreements with private companies to support their programmes for applications of micro-electronics. This support takes the form of subsidies which can amount to 40 percent of R&D personnel and contract costs, and 20 percent of investments (ITC, 1984).

German machine tool manufacturers, and other industries may also receive export financing assistance from their participation in the German government's "special-function banks," which provide aid to foreign countries. Such assistance takes the form of so-called "Humes guarantees" for exports of products which, in

turn, allow exporters to receive preferential financing rates from either special-function banks or private sector banks (ITC, 1984).

In the case of industrial robots in the period 1974-1979, the German government funded industrial robot research and development programmes to the level of about \$13 million, allocated to German industrial firms engaged in robot production in the form of grants (Baranson, 1983; ITC, 1984; Massen, 1983).

Since 1980, the "Fertigungstechnik" programme established by the BMFT, with a total budget of \$100 million from 1980 to 1988, has indirectly benefitted the German machine tool and robotics industry, by assisting small and medium sized German firms through grants and preferential loans to finance research and development activities (ITC, 1984).

In 1984, the government approved funding of about \$1.1 billion to stimulate the development of advanced-technology industries in Germany which included German machine tool makers and in 1985, the government established support programmes of some \$200 million for the use of computer-aided design and manufacturing, software and robotics in German industry sectors.

As can be seen from the above, the German government has provided only marginal support to the German machine tool sector. Most of the German government policies which have profited German

machine tool makers have been indirect in that these policies have been designed to benefit the entire German industrial sector (Daly and Jones, 1980).

9.5.3 Government Policies in the Advanced Materials Sector in Germany

Research in advanced ceramics in Germany has been funded at a total level of nearly \$50 million over the past 15 years. This research, which dates from 1974, was initially sponsored by the BMFT in support of programmes dealing with advanced ceramic components for vehicular gas turbines (Hutton, et al., 1977). Almost half of the funding was provided by industry. The initial programme ended in 1983, and a new programme called "Car for the year 2000" was begun in 1984.

No other explicit policies have been enacted by the German federal or Laender governments to facilitate research, development or engineering of advanced materials (Kocka, 1980). Several comprehensive universities and technical colleges have initiated work with advanced ceramics, and some of the funding for this research effort originates from the German federal government departments and agencies (Balmer, 1983). Such funding, however is provided for advanced research without specifying advanced materials as the research focus. Similarly, several German chemical firms, including I.G. Farben A.G., have undertaken research and development work on advanced ceramics as well as

polymers. Here again, there has been no funding or other kind of support for these efforts from the German federal and Laender governments.

9.6 CONCLUSIONS

German federal and Laender governments have enacted only a few policies to assist German advanced technology industries. The limited assistance provided to these industry sectors has resulted from the macroeconomic policies of the German federal government designed and implemented to assist all German industrial sectors, without targeting particular sectors or technologies (Rubenstein, 1977; Franzmeyer, 1979; Lederman, et al., 1986).

There are no formal German government and industry coordinating mechanisms or offices for science and technology activities. The German autonomous science and technology associations such as the MPG and the DFG are very successful in coordinating science and technology efforts among all German establishments engaged in such activities.

The German government support and funding of research and development efforts may be marginally classified as policies designed to assist specific industry sectors. In terms of public expenditure theory, such government assistance however may be readily accepted and considered as normative policy. It can be

readily prescribed as a public welfare activity effort in order to avoid socially undesirable duplication of research activities and to promote socially acceptable advancement in science. It can be stated with some certainty that German government policies with regard to German industry in general, and German export sectors in particular, have been designed and implemented in accord with free market principles at home and in world markets (El-Agraa, 1985). The German government's policy of not interfering with free market mechanisms has been applied with some consistency during periods of prosperity as well as economic decline. For example, during the 1978 to 1987 period, the German machine tool industry, clearly one of the most important German export sectors, lost about 40 percent of its world-wide sales of machine tools to Japanese manufacturers. In spite of these very large losses, and in spite of the fact that Japanese machine tool makers did not conduct their export sales according to accepted "rules," the German government chose not to tamper with free market forces on behalf of their machine tool industry (Daly, et al., 1985).

In the light of the above, the obvious question is how well has German industry performed, especially in comparison to nations which have attempted to advance their industry sectors by various policies which interfere with market forces?

The German microelectronics industry has had a minor presence in world-wide microelectronics sales. Germany, however, has

maintained its share of the world market over time. In 1964, Germany's microelectronic production represented about 1.4 percent of the world's total; by 1975 Germany's share had increased to 1.6 percent, and by 1987 it had further increased to 1.7 percent. Clearly not a spectacular performance, but one which cannot be categorized as a failure.

Perhaps more important the German government has expended essentially no public monies in direct support of its microelectronic industry sector. By comparison, France, with its native microelectronic sector in complete disarray in 1988, has expended approximately \$1.5 to \$2.5 billion on the French microelectronic industry over the last three decades.

In the machine tool sector, Germany's experience is somewhat different. As in the case of microelectronics, the German government has provided only very marginal support to German machine tool makers. German machine tool exports were very large until the late 1970's. In the post-World War II period, German machine tools constituted, at various times, between one-third and more than one-half of the total world-wide sales of machine tools (Peacock, 1980). Starting in the late 1970's, the Japanese machine tool industry began to penetrate international sales of machine tools, almost exclusively at Germany's expense, and captured about 40 percent of Germany's machine tool exports as well as increasing sales of Japanese machine tools in Germany.

A study of the voluminous technical, economic and international trade literature suggests that the Japanese success was not based solely on the technological superiority of their machine tools.

The cardinal reason for the Japanese success in increasing their machine tool exports and the German failure to prevent the Japanese from capturing their export sales, apparently lies in the superior Japanese export marketing organization and skills. To be more specific, the Japanese were able to offer far superior terms of sale than those offered by German machine tool export sales. The superior Japanese terms of sales included superior engineering and related consultation services, after-the-sale performance guarantees, replacement services, assistance in installation, training and initial after-the-sale supervision and, perhaps most important, much more attractive sales terms to the buyer. The latter included a host of Japanese innovations such as lease-back guarantees, lease of machine tools in place of outright purchase, payments scheduled in concert with utilization rates, delayed pay-back loans for purchases and others. One can assume, perhaps with some justification, that these superior after-the-sale incentives and advantages offered by the Japanese for sales of their machine tools represents a manifestation of still another set of industrial policies on the part of the Japanese government.

CHAPTER 10:
SCIENCE AND TECHNOLOGY POLICY
IN THE UNITED KINGDOM

10.1 INTRODUCTION

Over the last several decades, the economy of the UK has shown a modest secular growth pattern. In 1988, the GNP of the U.K. increased by 4.4 percent as compared with a 3.4 percent increase for both Germany and France and a 5.7 percent increase for both the U.S. and Japan.

The International Monetary Fund estimates for 1989 indicate that the GNP of the U.K. will increase by 3.3 percent as compared to a 2.8 percent increase in France and a 2.4 percent increase in Germany. In terms of international trade, however, the position of the U.K. is less favourable. In 1988, the current account balance for the U.K. was a negative \$26 billion, and this negative balance is projected to increase to \$30 billion in 1989. The Current Account balances for France for these two years are also negative, but much smaller -- \$4 billion in 1988 and \$2 billion in 1989. Conversely, Germany's current account balance in 1988 was positive and relatively large -- \$49 billion with essentially an identical estimate for 1989.

The trade balance for the U.K. in advanced technology products has deteriorated over the last decade or so, and is a contributing factor to the overall decline in the balance of trade for the U.K.

This has not always been the case. On the contrary, the U.K. in the past has been in the forefront among industrial nations in scientific activities and technological achievements (Aldcroft and Richardson, 1970).

The Royal Observatory at Greenwich was established as early as 1675, the Geological Survey in 1832 (one of the first in the world) and the Laboratory of the Government Chemist in 1843. By the early part of the 19th century, Parliament was accustomed to appropriating not insignificant public monies to support initially natural science but gradually other scientific enterprises (Matthews, et al., 1982).

Parliamentary recognition of the importance of research led to the creation of a Department of Science and Art in 1853, and the genesis of the Agricultural Research Council in the U.K. dates from 1909. The adoption of the National Insurance Act of 1911 provided that one penny per insured person was to be allocated to medical research (Daly, et al., 1983).

The U.K.'s scientific and technological inventions in the 18th and 19th centuries were adopted as a measure for scientific achievements world-wide. Equally important, U.K. scientific achievements were matched by technological advances and industrial innovations including steam powered transportation systems, textile machinery, aviation, food processing and others (Crafts and Thomas, 1986). These achievements continued throughout this century, with the development of the radar, during World War II, as an indicator of the quality of scientific and technological activities in the U.K. The U.K. can also claim numerous achievements in the post World War II decades up to the present time (Gibbons, 1984).

It has, however, been stated by many that during the last several decades, the application of scientific and technological advances in the U.K. has been modest (McIntosh, 1986). As stated by the Economist (January 14, 1989):

Britain lacks less for good inventions than for good technology. The electronic device foreseen by Mr. Brian Josephson while studying at Cambridge University won him a Nobel prize in 1973. But the lightning-fast Josephson junction (used to make computers go faster) is being perfected in Japan. The CT scanner invented by EMI's Mr. Geoffrey Housfield, which won him a Nobel prize in 1979, is now making American medical-equipment firms rich.

If anything, Britain's experience shows that the curiosity, frivolity and fumbling so cherished by British boffins are the best ingredients for creative success -- but just about the worst for turning ideas into profit-earning products.

Indeed some of the science indicators point clearly to a decline in the U.K.'s ability to apply scientific knowledge. For example, in 1960, over twenty percent of all patents granted by the U.S. Patent Office were granted to U.K. scientists. In 1983 this proportion had declined to 8 percent, and in 1986 to less than 6 percent (Hochstrasser, 1986). The British government has attempted to design and enact relatively comprehensive policies to correct these declines and to improve the performance of advanced technology industries in the U.K.⁽¹⁾ The results of these policies have been modest (Martin, et al., 1984).

10.2 SCIENCE, RESEARCH AND TECHNOLOGY PERFORMANCE IN THE UNITED KINGDOM

In the U.K., scientific, research and development and technology related activities are performed by four types of establishments: a) universities; b) British government owned and managed laboratories and research institutions; c) private industry; and d) independent nonprofit organizations.

A report from the OECD (1986) provides an approximate measure of the distribution of scientific and research activities by these four types of establishments in terms of total expenditures:

Universities	60%
Government (in-house)	24
Private industry	14
Private nonprofit	<u>2</u>
	100%

Government funding, however, is cardinal in the U.K. with approximately 48 percent of all research and development in the U.K. funded by the British government.

10.2.1 Universities

Some of the principal performers of basic research and a significant portion of applied research in the U.K. are the universities.

Since 1966, higher education in the U.K. has consisted of universities and polytechnics. U.K. polytechnics were established in 1966 in order to provide technical and applied education. There are at present 29 polytechnics in the U.K. The cardinal characteristic of these polytechnics is that these are principally teaching institutions. Polytechnics were established primarily in response to the needs of the communities or regions in which they are located. The curricula of the polytechnics emphasize science and engineering applications, but these are generally broadly based. Polytechnics have over time become involved in some

research and development activities, particularly applied research serving the needs of local industry sectors.

Universities in the U.K. are autonomous institutions but a significant proportion of their funding is provided by the government. Some universities receive modest additional funding, from their own endowments, local authorities (mainly for student stipends), industry, and other private sources.

British government support for universities is derived from two sources: the University Funding Council (UFC), which provides support to the universities primarily in the form of annual block grants from public monies, the internal disposition of which is determined by the recipient university; and from the five Research Councils (Science and Engineering, Medicine, Natural Environment, Agriculture and Food, and Economic and Social Science), which provide competitively awarded research grants from public monies to university scientists as well as some fellowships and scholarships.

The combination of support to the universities for scientific research and development and related activities from these two sources (UFC block grants and the five Research Councils) comprises what is known as the U.K.'s "dual-support system" for academic science, research and development and related activities.

The university system in the U.K. has performed well in various scientific, research and development endeavours. However, the system, on the admission of the U.K.'s own authorities, may be handicapped in its science and related activities by a shortage of experienced research personnel and scientists in some of the British universities in some disciplines of science.

The Advisory Board for the Research Councils (ABRC) in 1987 recommended in the light of this possible shortage, a so-called RTX classification scheme of the U.K. universities. Under this classification, universities rated Type R are those with substantial research activity and capability across all fields; Type X are those with substantial research capability in particular fields, and Type T are those universities which are capable of pursuing the research and scholarship necessary to support teaching, but not able to undertake advanced research.

This attempt by the ABRC met with significant opposition on the part of the universities (Phillips, 1988). The merits of such a classification system is of secondary importance here. It is important to note however, that in the light of the above, scientific and related activities by the universities in the U.K. may be handicapped because of the absence of "economies of scale" in some U.K. academic institutions.

In response to the need for more applied research, the Engineering Research Council has established various British universities Interdisciplinary Research Centres -- research units with a strong emphasis on applied research and development activities. The activities of these Centres have been subjected to some criticism by university scientists who are engaged in basic research activities. For example, a Committee consisting of chemists engaged in research at various U.K. universities responded in the following way to a request by the UFC in 1987 to provide analyses of these Centres as well as on the RTX classification; according to Science (Jan. 3, 1988):

The chemistry committee also rejects the notion of teaching-only departments. But it warns against a tendency to put excessive emphasis on applied (or even strategic) research in universities. The committee expresses particular concern about the Science and Engineering Research Council's (and the British government's) current enthusiasm for university-based Interdisciplinary Research Centres. It says that these have been cutting directly into the budget for fundamental research and that as a result research in core chemistry is in serious danger since support has been reduced to an unacceptable level by the movement of existing funds into new areas.

The critical issue which needs to be highlighted is that here again the issue of "economies of scale" in scientific activities is raised.

A more widely accepted policy to increase applied research in universities and to encourage university-industry cooperation in research, is the establishment of science parks. About 20 science

parks, generally located near universities and in proximity to advanced technology firms, have been established or are planned in the U.K. (Lowe, 1985).

10.2.2 Government Laboratories

The principal performers of scientific activities and research and development within the government sector in the U.K. are the various research establishments and units subordinate to the British government's Five Research Councils: the Agricultural and Food Research Council (AFRC), the Economic and Social Research Council (ESRC), the Medical Research Council (MRC), the Natural Environment Research Council (NERC), and the Science and Engineering Research Council (SERC). In addition to providing support for research conducted in U.K. universities, each of the Councils also conducts research within its own establishments.

Each of the Five Research Councils is an autonomous body established by Royal Charter. They are financed primarily through the Science Budget of the Department of Education and Science, although the five Councils may also receive funding from other British government departments and agencies to undertake contract research.

The SERC, the principal British government agency for science and technology, was established in 1965 as the successor to the

previous Department of Scientific and Industrial Research. The primary responsibility of the SERC is to promote scientific and research activities in all areas of basic and applied science and engineering in the U.K., other than the specialized areas covered by the AFRC, MRC and NERC. During the 1965 to early 1970's period, the SERC concentrated on funding research in areas such as nuclear physics, astronomy, and basic chemical sciences. Since the mid-1970's the SERC's funding has also been extended to applied research, development and engineering projects.

The SERC operates four major research establishments, established as specialized research centres and operating facilities that are beyond the resources of academic institutions. These establishments include the Daresbury Laboratory (engaged in nuclear structure research), the Royal Greenwich Observatory, the Royal Observatory, Edinburgh, and the Rutherford Appleton Laboratory (engaged in particle physics, laser-produced plasmas and space research).

The NERC was established in 1965 to conduct research in the physical and biological sciences that relate to the natural environment and resources. It has nine component institutes engaged in research related to atmospheric, terrestrial and marine environments.

The MRC was established in 1920 to promote research in all areas of health and disease. It operates three major research establishments and some fifty smaller research units associated with medical schools and hospitals.

The AFRC was established in 1931 to promote the advancement of scientific knowledge relevant to agriculture, horticulture and food and the application of this knowledge to related industries. The AFRC has eight research institutes under its direct control and is also responsible for 15 independent state-aided agricultural research institutes.

The ESRC encourages and supports research in the social sciences, particularly research that might assist with the formulation of public policy.

10.2.3 Industry

Scientific, research, development and engineering activities undertaken by industry in the U.K. include such activities as are conducted by private companies, public corporations, and a number of industrial research associations. The latter are usually found in sectors of the economy dominated by smaller enterprises.

A breakdown of expenditures for research and development performed by industry in 1975, 1978 and 1981 is shown in Table 10.1.

TABLE 10.1

Expenditures on R&D Performed by Industry
by Broad Product Group:¹ the United Kingdom
1975, 1978 and 1981
(L Million)

	<u>1975</u>	<u>1978</u>	<u>1981</u>
All product groups	1,340.1	2,324.3	3,792.5
All products of manu- facturing	1,293.4	2,243.3	3,549.0
Chemical & allied products	245.4	424.7	654.7
Mechanical engineering	103.4	181.1	276.0
Electronics	279.0	649.6	1,153.3
Other electrical engineering	73.0	100.8	120.8
Motor vehicles	88.3	129.7	180.4
Aerospace	291.5	424.6	762.9
Other manufactured products	212.8	332.6	401.0

¹ Includes capital as well as current expenditures.

Source: Department of Trade and Industry, as cited in
"Industry Carried Out R&D Worth L 3.8 bn in
1981," British Business, 9 December 1983,
p. 751.

Of the total research and development performed by industry in 1981, nearly 94 percent was related to products of manufacturing. By far the largest concentration of this research was in electronics. Electronics and aerospace accounted for more than one-half of industry research and development in 1981. Chemical and allied products were ranked third in terms of research and development, followed by the mechanical engineering sector and motor vehicles.

The significant research and development activities in electronics by U.K. firms have been criticized because of the heavy reliance by U.K. electronics and aerospace firms on defence procurement (Maxwell Stamp Assoc., 1969; Gummatt, 1980). In 1986, for example, more than one-half of the total production of U.K. electronics firms was allocated to defence-related products. Out of the top ten European defence electronic companies in 1987, five were from the U.K. (GEC ranked first; Plessey fourth, British Aerospace fifth, Ferranti seventh, and Racal tenth).

It has been argued that such a heavy concentration on defence-related products by U.K. electronic firms, may leave these firms with a limited ability to pursue civilian electronics markets. Indeed, these concerns and criticisms of the electronics sector have been put forth by industry experts and academic and government officials in the U.K. and elsewhere (Hochstrasser, 1986; Chandler, 1980; Caves, 1974). The absence of major innovations in the microelectronics industry (except for INMOS' out-

standing success with microprocessors) during the last two decades provides some credence to these charges. It must be noted, however, that since 1985, U.K. electronic firms, notably GEC and Plessey, have deliberately attempted to reduce their reliance on defence contracts (Palmer, 1987).

It is too early to tell whether or not these changes in market orientation will bring about advances in non-defence microelectronic products. The other alleged problem area which may have a direct impact on industrial research and development activities in the U.K. is the continuous attempts by British firms to reorganize their activities by mergers, acquisitions, partial sell-offs of departments and related activities (Sharp, et al., 1987).

In 1985, for example, GEC attempted to take over Plessey only to be prohibited from doing so by the Monopolies and Merger Commission of the British government. In 1988, again GEC attempted to absorb Plessey, this time with the assistance of the German firm Siemens. In early 1989, GEC faced dismemberment from a consortium financed by Barclays Bank, as well as from the combination of General Electric Corporation from the U.S. and British Airways. Other possible participants in such takeover activities during the last several years have been Phillips (Holland); CGE (France); GEC (UK); Thomson (France) and others.

Such activities are not new to industry in the U.K., rather a large number of complete or partial takeovers, rationalizations, purchases, etc. have taken place in the past (Prais, 1976). For example, GEC has a 5 percent interest in France's Matra; Plessey owns 49 percent of Italy's Electtronica; British Aerospace bought Rover in 1984; Rolls-Royce in 1989 purchased for \$520 million the Northern Engineering Industries (NEI); the British Smith Industries in 1987 purchased its rival the Lear Siegler Corporation of the U.S. and so on. Not all of these corporate mergers, takeovers and acquisitions result in net losses to the U.K.'s economy. On the contrary, some of these provide Euro-competition to the U.S. and Japan, while others result in improved competitiveness in world markets.

There are, however, a number of knowledgeable authorities who claim that the sheer magnitude and frequency of these activities reduce planning ability and the execution of appropriate research and development programmes by the enterprises involved (Hughes and Kumar, 1981; Kumar, 1984; Hochstrasser, 1986).

10.2.4 Private Nonprofit Institutions

Private non-profit institutions involved in the performance of research, development and engineering activities account for only a minor portion (about 2 percent) of the overall research and development effort in the U.K.

10.3 GOVERNMENT FUNDING AND ASSISTANCE FOR SCIENCE AND TECHNOLOGY ACTIVITIES IN THE UNITED KINGDOM

The government of the U.K. utilizes several government departments and agencies as a funding source for scientific, research and development activities in the U.K. The principal agencies involved are the Department of Trade and Industry, the Department of Scientific and Industrial Research, and the Five Research Councils, in particular the SERC.

In very broad terms, the British government's funding for science and research and development activities increased up to the early 1960's and declined from then until the mid-1980's when the government began to increase public monies for science and related activities as part of a deliberate policy to enhance the status of science and technology in the U.K.

Between 1959 and 1963, funding for research activities by the Department of Scientific and Industrial Research increased by about 320 percent. In the mid-1960's, the funding began to decline. In 1971 the rate of annual increase in funding had declined to 4 percent. Gibbons (1974) reported on this as follows:

Because of the increasing pressure on government resources of other more directly appealing or social claims, we are now probably past the point of maximum growth rate of resources for science.

This creates difficulties which are increased by



'sophistication' (a term used to express the fact that it becomes more expensive to make equivalent advances to knowledge) and by the growth of 'big science' (where the threshold of expenditure needed to achieve any worthwhile result tends to rise continually, as the fields of nuclear physics and radio-astronomy illustrate).

This growth of expense of what might be considered the same 'amount' of good science can partially be offset, for example, by increasing international collaboration and by selectivity in the support of science.

The consequence of an increasing need for selectivity in support of science and for an increasing amount of international science at a time of decreasing popular approval of science will be that Research Councils will have to become increasingly well-informed about national needs and objectives, so that they may try to deploy scarce resources in the most appropriate direction, and be seen to be doing so.

Though this is a task of considerable complexity, it is also one of immense importance and we regard it as imperative that those responsible for determining scientific priorities should be fully informed of, and should pay due regard to, government policy and national needs.

Throughout the 1970s and mid-1980s, the funding for science and technology by the British government remained relatively constant in current money terms, which means it declined somewhat in real terms. Since 1985 the British government's funding of science and related activities has increased at a modest but steady rate (Phillips, 1988).

Another British government agency for the advancement of British science and technology in industry is the Department of Trade and Industry (DTI). Since 1980, DTI direct support for

science and technology has increased significantly. In 1980, the DTI provided for science and technology activities \$227 million or about 6 percent of its budget. By 1985, DTI funding for science and technology activities, had increased to \$654 million and is projected to increase to about \$800 million in 1989. DTI assistance to British science and technology activities may be grouped in the following categories:

- a) funding of the four British Industrial Research Establishments (IRE's); the National Physical Laboratory (NPL); the National Engineering Laboratory (NEL); the Warren Sperry Laboratory (responsible for environmental sciences); and the Laboratory of the Government Chemist;
- b) funding assistance to private firms for selected research and development projects;
- c) measures designed to promote technological collaboration among British firms; and
- d) activities designed to promote the application of advanced technologies in the U.K.

The funding of selected research and development projects by private firms is of special interest because this funding represents essentially sectorial or target industry support by the British government. Barber and White (1987) describe this funding as follows:

Support for Innovation (SFI): This is a comprehensive facility available to all sectors, offering selective financial support to firms undertaking R&D projects. The main form of assistance is grant aid of up to 25% of eligible costs for development projects and up to 50% for research projects.

The Microelectronics Industry Support Programme (MISP): This scheme (started in 1983) provides for total grant assistance of L120m over seven years for R&D and/or capital projects which contribute significantly to the improvement of the competitiveness, strength and independence of the UK microelectronics industry. An earlier MISP scheme which provided total assistance of L55m closed in 1983.

The Fibre Optics and Optoelectronics Scheme (FOS): This scheme is similar to MISP but directed at the UK fibre optics and optoelectronics industries. It was launched in 1981 with a total budget of L25m which has since been increased to about L55m. Software Products Scheme (SPS): This scheme provides support in the form of grants of up to 25% of eligible project costs for the development and marketing of software products (packages). The current level of expenditure under this scheme is of the order of L6-7m per annum.

The budget of the SERC represents another British government funding source for research activities. As noted previously, the SERC promotes research in all areas of science and engineering with the exception of the more specialized areas covered by the AFRC, MRC and NERC. Research performed in-house in the SERC's subsidiary research establishments accounts for about 35 percent of its total research and development expenditures. A number of joint research projects have been undertaken in collaboration with government departments and nationalized industries. In addition, the SERC has been utilizing a variety of methods for encouraging

university and industry collaboration in research on engineering and applied problems of national importance.

The activities of the SERC are carried out by four subordinate Boards -- Engineering; Astronomy, Space and Radio; Nuclear Physics; and Science. The Science Board accounts for about 28 percent of the SERC's total R&D expenditures; the Engineering Board, about 25 percent; the Nuclear Physics Board about 23 percent; and the Astronomy Space and Radio Board about 18 percent. The remaining 7 percent of the SERC's expenditures goes to central administrative support. The SERC relies on the advice of the four subordinate Boards as well as close to 70 committees, sub-committees and panels (each typically with 10 or 12 members) in allocating its budget support.

The Engineering Board conducts and supports research in all areas of engineering and technology. The distribution of its 1986 research and development expenditures by subject area was as follows:

Information Technology	21.0%
Materials	12.5
Machines and Power	12.2
Engineering Processes	9.7
Marine Technology	9.5
Environment	6.6
Teaching Company	5.7

Biotechnology	3.8
Polymer Engineering	3.4
Energy	1.6
Support for Establishments and Other Domestic Facilities	12.6

The Astronomy, Space and Radio Board of the SERC covers astronomy and solar system studies, and provides access for UK astronomers to a wide range of facilities, both domestically and internationally. The breakdown of the Boards' 1986 expenditures by principal subject area was as follows:

Astronomy	17.5%
Solar Systems	6.9
International Contributions	26.7
Support for Establishments and Other Domestic Facilities	50.2

The SERC's Nuclear Physics Board supports fundamental research in particle physics, which is carried out wholly in international facilities, and in nuclear physics using both UK and overseas facilities. The distribution of its R&D expenditures by broad subject area in 1986 was as follows:

Particle Physics	8.8%
Nuclear Structure	3.7
International Contributions	56.8
Support for Establishments and Other Domestic Facilities	30.8

The Science Board of the SERC supports basic research in the 'core' sciences -- biology, chemistry, physics and mathematics-- which provide the foundation for the activities of the other science-based research councils and the UK's science-based industries. The breakdown of its 1986 expenditures by broad subject area was as follows:

Chemistry	21.1%
Biological Science	20.2
Physics	10.7
Mathematics	3.8
Other Research	3.8
International Contributions	9.5
Support for Establishments and Other Domestic Facilities	31.0

The SERC and the four other Research Councils account for about eighteen percent of the total amount spent by the British government on research and development in the U.K. In 1988, the British Department of Education and Science proposed to increase its support to the five Research Councils from \$1.24 billion in 1988 to \$1.44 billion in 1989, an increase of sixteen percent. The allocation of this funding among the five Research Councils, will be based on the advice provided by the ABRC.

10.4 RECENT SCIENCE POLICIES IN THE UNITED KINGDOM

In the early 1960's, British science research and development activities began a downward slide, partly brought about by reduced spending.

By 1971, the annual real growth rate of science research and development expenditures in the U.K. had fallen from 15 to 18 percent in the mid-1960's to about 4 percent, with further reductions in prospect. In the mid-1960s, the U.K. had the second highest research and development budget among OECD member countries. By the mid-1970's, the U.K. ranked fourth among OECD members in research and development activities.

It has been reported that this decline in funds was due to a lack of direction in the U.K.'s science and technology policies, and some argue that the British government in the 1970s had essentially no centralized science and technology policy but rather a series of individual departmental policies (Dalyell, 1983; Gummatt, 1980). Science and research policies in the U.K. in the 1970's were not formulated by a central body but rather by a series of committees at various levels, such as the ABRC, the Advisory Committee on Applied R&D, and the Defence Scientific Advisory council.

Indeed a number of scholarly papers on the status of U.K. science and technology in the 1970's suggest a drift in policies and merger accomplishments in science and technology related activities (McIntosh, 1986; Peacock, 1980; Danic, 1980). The science and technology policies were reversed by the British government under Prime Minister Thatcher in the 1980's.

In 1983 the British government announced plans to improve significantly science and technology policy coordination between various government agencies and to strengthen the role of the Chief Scientist in the Central Policy Review Staff.

More important, a number of entities of the British government and of the U.K.'s science and technology establishment began critical reviews of the science, technology, research and development, and advanced industry status and activities in the U.K. A number of public documents resulted from this effort.

In early 1987, the House of Lords published critical report on the U.K.'s science effort. The report proposed that a Minister of Science with cabinet rank be appointed. In July 1987, the government replied with a White Paper in which significant changes in science policy were outlined.

One of the key provisions was the recommendation for a "collective Ministerial consideration under the Prime Minister's

leadership of science and technology priorities," which resulted in the establishment of a Cabinet Committee on science and technology chaired by the Prime Minister.

According to Phillips (1988) the Committee has four principal responsibilities:

- a) considering important ad hoc issues -- for instance, present questions about the UK's involvement in space research and in CERN;
- b) considering major policy developments on science -- perhaps, for example, the Government's response to the ABRC's Strategy Advice;
- c) overseeing reviews of particular parts of Government-funded R&D in relation to general policy considerations. The relationship between Government-funded and industry-funded research might be one such concern;
- d) undertaking an annual review of science funding priorities as a major input to the Public Expenditure Survey process, beginning in 1988.

The ABRC, in a report published simultaneously with the White Paper, also expressed its own concern at ". . . a lack of purposeful direction, nationally, in the redeployment of the university research effort, both between and within institutions." One of the principal recommendations of the ABRC was the creation of a number of interdisciplinary, university-based research centres, focused on "strategic" science. In August 1987, the SERC announced seven science and technology areas for which such centres will be established. The Centre for Exploitation of Science and Technology in the autumn of 1987 began efforts to

identify other areas of science and technology which would be suitable for commercial exploration.⁽²⁾

In late 1987 the Prime Minister, Margaret Thatcher (after her third successive general election victory and partly in response to the concerns expressed) significantly modified the existing science and technology policy-making apparatus. She made administrative changes by placing the emphasis on applied research and by soliciting industry's views of appropriate science and technology policies.

In place of the Advisory Committee on Applied Research and Development (ACARD), which during the last decade had functioned as the principal science and technology advisory body to the Prime Minister, a new organization -- the Advisory Committee on Science and Technology (ACOST) was formed, with the responsibility of reporting to the Prime Minister through the Cabinet office. Another new organization, the Centre for the Exploitation of Science and Technology was also established with the mandate to work closely with ACOST. The Centre was mandated to provide U.K. industry, government and the academic community with advice on the most commercially promising areas of science, that is, applied as opposed to basic research. This focus on applied research presented the members of the two new British Government agencies with an opportunity to emphasize industry research priorities for research and development. Essentially all ACOST members were

research managers and chief executives within the private sector, and the Centre was funded by private sector-industry subscription. Thus, the British private sector become an important factor in the principal science and technology policy making activities in the U.K. in 1987.

The need to reemphasize applied research and development in the U.K. was not limited to the opinions held by industry. On the contrary, the need to concentrate on applied research had been expressed by other interested parties in the U.K. For example, an ABRC report published in 1987 which focused on the criteria for the selection of research and development activities in the U.K. emphasized such applied research components as exploitability (the potential for profitable industrial and commercial use); applicability (the potential for uses leading to social and environmental benefits); and the significance of research for education and training (Phillips, 1988). Sir David Phillips summarizes this as follows: "The implication . . . is that judgments of potential utility should play a greater part in determining the relative level of effort to be devoted to different fields of basic research." (Phillips, 1988).

10.5 THE UNITED KINGDOM GOVERNMENT'S SUPPORT FOR ADVANCED TECHNOLOGIES

10.5.1 The Microelectronics Sector in the United Kingdom

Most governmental policies directed at the U.K. microelectronic industry have consisted of a series of government grants to the native microelectronic sector.

In 1968, the British Ministry of Technology made the first grant by providing International Computers Ltd (ICL) with financial support of about \$12 million per year for the period from 1968 to 1976. The British government also allocated about \$12 million in this period for applied research in the microelectronic industry to be undertaken through the Advanced Computer Technology Project (ACTP). An additional \$8 million per annum was provided by the British government to seven English microelectronics firms to stimulate software development. For the British microelectronic components industry, the Department of Industry provided funding of \$4 million per annum from 1973 until 1977 with additional support from the Defence Ministry of about \$5 million per year.

In 1978, the BDI announced the availability of a further \$140 million of funding over a three year period to integrated circuit manufacturers operating in the U.K. Almost simultaneously, another U.K. government agency, the National Enterprise Board (NEB), announced an investment of \$100 million in an attempt to

establish a new world-class semiconductor manufacturer called Inmos (Mackintosh, 1979).

The NEB has been the principal source of government funding to the microelectronics industry over the last several decades. The SIA reported (1985) on these NEB activities as follows:

The National Enterprise Board agreed to put up \$115 million to establish Inmos. Inmos is supposed to establish a UK capability to design and produce state-of-the-art memory circuits (i.e., the 64K MOS RAM).

The Department of Industry is involved with several major endeavors: MAP, the Microprocessor Applications Project; the National Computing Centre "Awareness Program"; the Microelectronic Support Scheme; and MISP, the Microelectronic Industry Support Programme. MAP is to help both electronics and non-electronics firms to quickly incorporate microprocessors into their manufactured products so that they will become more competitive in world markets. This \$30 million program is getting another \$80 million infusion. Some discussions have placed a total expenditure at \$230 million. The Awareness Program holds organized seminars in an effort to locate and train 50,000 decision makers for microprocessors at a cost of \$20 million. The Microelectronic Support Scheme expired by the end of 1979. The accumulated cost was \$150 million. MISP is the most important of the DOI electronic endeavors. It is intended to deal with high volume production to manufacture standard products such as microprocessors, LSI memories, etc.; sponsorship of companies to produce custom parts will also cover related test equipment required for manufacture; and development of the local semiconductor industry infrastructure. MISP does not limit its funding to British-only companies but has and will continue to fund foreign multinationals wanting to locate in the UK. MISP has an estimated \$140 million available (SIA, 1985).

During the same period, in order to increase the use and application of microelectronic products in the economy, the DTI established the Microelectronics Application Project (MAP) to

encourage industries in the U.K. to use microelectronic devices both in products and in production facilities. MAP consisted of several components including a programme which provided seed money to companies with plans to incorporate microelectronics in their products for the first time. From 1978 to 1985, the British Government's expenditures for MAP programmes was estimated at about \$160 million. In 1985, MAP programmes were reduced in scope and expenditures, and spending by MAP between 1985 and 1988 has been estimated at about \$50 million.

In order to achieve effective research and development activities, economic size of production facilities and marketing efforts by the British microelectronics sector, it was the policy of the British government during the 1960's and 1970's to support mergers or consolidations in the U.K. microelectronics sector. Several such consolidations did take place in the 1960's and 1970's (deCarmoy, 1978).

The British government has also attempted to provide policy guidance to the native microelectronic sector by establishing in the 1970's a series of British government councils with a broad mandate to formulate and execute government policies for industry sectors including microelectronics.⁽³⁾

These attempts by the British government to assist the microelectronics sector in the 1960's and 1970's were only partially

successful (Khalilzadeh-Shirazi, 1974; Daly et al., 1985). Four U.K. companies, Plessey, Ferranti, Marconi, and the General Electric Company (GEC) comprised the bulk of the native micro-electronic industry in the U.K., prior to the sale of Marconi to Ferranti (Cabinet Office, 1978). Total annual sales of these four companies in the late 1970's was estimated to be \$50 million, only about 6 percent of the annual sales of the microelectronic industry's leader in the U.K., the U.S. firm of Texas Instruments. During the 1980's the British government has attempted another approach, that of funding large scale projects, more specifically, establishing and funding the Alvey Programme in 1983 -- a large scale project similar to the French grands programmes.

The Alvey Programme for Advanced Information Technology, named after John Alvey, the chairman of the British government commission which recommended it, was viewed as the U.K.'s response to the French national programmes or to Japan's Fifth Generation Computer Project. The Alvey programme represented a British government-industry joint venture focused on key research objectives in several areas of the microelectronics industry. The programme was intended to extend scientific and technical knowledge rather than advance the frontiers of microelectronics technology (OTA, 1984; Palmer, 1987).

The initial funding for the Alvey Programme approximated \$350 million, of which about \$320 million was provided by the British

government; \$64 million by the British Ministry of Defence (MOD) and \$176 million by the DTI. The programme was administered through the DTI in collaboration with the MOD and the SERC. Mechanisms for channelling funds to the Alvey Programme participants reflects this cooperation. The SERC managed the participation of the British academic institutions, the MOD supervised defence-related activities and the DTI supervised private sector participants.

The programme was designed to operate as a native U.K. research effort with technical information shared among the participating partners. The principal objective was to provide the results of the programme essentially exclusively to the U.K.'s entities.

. . . participation by non-U.K. multinationals should be permitted only when they are able to contribute a particular asset to the programme, where the results of their involvement will be available to benefit U.K. industry as a whole, and where the relevant technical information will not leak from the U.K. Full exploitation by U.K. industry should be encouraged and at an early a stage as possible (OTA, 1986).

In 1987, four years after the initiation of the Alvey programme, there were nine technical areas of concentration in the programme. The categories of technical interest and approximate allocation of funding are presented in Table 10.2.

TABLE 10.2

Components of the Alvey Programme, 1987

<u>Areas of Research Concentration</u>	<u>Number of Projects</u>	<u>Approximate Allocation of Funding</u>
Information Knowledge-Based Systems (IKBS)	36	10 %
Very Large Scale Integration (VLSI)	36	26 %
VLSI Architecture	7	3 %
CAD for VLSI	8	9 %
Software Engineering	28	17 %
Man-Machine Interface (MMI)	8	14 %
Large Scale Demonstrators	4	9 %
Infrastructure and Communications	2	6 %
Comtemplated: Declarative Architectures and Systems	<u>0</u>	0 %
	129	

Source: Alvey Programme, Press Release, U.K. Embassy,
Washington, D.C., 1988.

The formation of consortia composed of companies, university teams, and research establishments was a requirement for participation in the programme. The average consortium consisted of four or more partners, two or three companies, and one or two universities. Table 10.3 identifies the overall distribution of participation in the Alvey Programme.

A review of individual Alvey projects and participants shows that of the 53 private firms which participated, 16 were involved in more than one research project, with the British firm GEC represented more than any other with participation in 28 separate projects. Within the academic sector, 31 of the 40 universities were participating in more than one project, with Cambridge University participating in 16 projects. Table 10.4 presents the 36 individual technology projects comprising the major thrust of the Alvey Programme in 1984.

The ultimate results of the Alvey Programme and an assessment of its impact on the British microelectronics industry must wait for the completion of this large project in the early 1990's. There are indications, however, that this programme has already resulted in significant improvements in the British micro-electronic sector, especially in terms of advanced technology diffusion (OTA, 1986; Pickering and Sheldon, 1984).

TABLE 10.3

Participants by Type in the
Alvey Programme, 1987

<u>PARTICIPANTS</u>	<u>NUMBER</u>
Companies	53
Universities	40
Polytechnics	6
Research Establishments	<u>5</u>
TOTAL	106

Source: Alvey Programme, Press Release, United Kingdom Embassy,
Washington, D.C., 1988.

TABLE 10.4

Technology Components of the
Alvey Programme, 1984

Enhanced rate RIE
Dry etching for VLSI
Plasma processing technology
Gas phase investigation
3rd generation RIE system
Ion surface interactions
Implant and diffusion
Impurity and defects
Analytical techniques
Electron tunnelling
Two dimensional model
Model evaluation
Interactive model
2 and 3D device model
Direct wire study
E-beam resists
Microlithography
Variable shaped E-beam
Chrome mark etching
Critical mask measurement
SEM failure analysis
Reliability of VLSI
CMOS-SOS
Bulk CMOS process
UHS bipolar
CDI bipolar process
Bulk CMOS
Multilevel metal
Dynamic recoil mixing
Si MBE for device fabrication
MBE for silicon VLSI
Silicon on insulator

Source: Alvey Directorate, DTI Press Release, 1985.

The present status and the future of the microelectronic sector in the U.K. as of 1989 is not clear.

On the one hand there exists considerable pessimism in some quarters about the future of microelectronics in the U.K. In a recent report for the National Economic Development Council, McKinsey and Co., a management consulting firm, reported the near fatal status of microelectronics in the U.K. Recent reports by the OECD anticipated a trade deficit in electronics for Western Europe of \$30 billion by 1992, of which a large portion will be carried by the U.K. (OECD, 1986). A distinguished industry expert, describing attempts to direct large scale projects such as the Alvey Programme, stated in 1984 that "the UK's major difficulties arise from the pervasive lack of incentives in its system of mission-oriented R&D," and describing the overall performance of such large scale projects: "On balance the UK effort has probably been the least successful. . ." (Ergad, 1984).

These views are not shared by industry in the U.K. Sir John Clarke, the chairman of Plessey, called McKinsey's criticisms "a monstrous travesty of the facts." In the autumn of 1988 the Economist, stated the following: "Executives in other companies are talking about opportunities rather than retreat. Elsewhere, stockmarket analysts, long critical of the European electronics sector, are beginning to recommend it to investors. Such optimism

is not only new, but, looking at electronics sector by sector, appears reasonably well founded." (Economist, August 6, 1988).

10.5.2 Governmental Assistance to the Machine Tool Sector in the United Kingdom

The U.K. machine tool industry has experienced a significant decline. The U.K. domestic machine tool firms have declined in number (partly as a result of the government's policies to rationalize this sector of the economy), production statistics show a sharp downturn, while the imports of machine tools into the U.K. have rapidly increased (Ministry of Technology, 1961; Pavic, 1980).

A brief summary of the past British government programmes for the machine tool industry provides a point of departure for a review of recent governmental policies regarding the U.K. machine tool industry in the 1980's.

In the inter-war period it was a protected industry, and only those types of machine tools not produced in this country were admitted free of duty. More recent examples of government support included a 'pre-production order scheme' in the 1960s designed to overcome user-conservatism; under this scheme, technologically-advanced machines of an experimental (and therefore expensive) nature were bought by the government and then lent free to industrial users for an extensive 'trial period.' A further scheme, which lasted until 1970, was intended to encourage the purchase of numerically-controlled machine tools; the government guaranteed to repurchase any unwanted machine tools and to pay the manufacturer for any reconditioning or reselling costs. A more recent scheme, under the Industry Act of 1972, provided a 25 percent subsidy to

the costs of developing and launching of new machine tools, and 15-20 percent grants for projects to modernize and expand capacity; about L30 million had been authorized on this basis by the end of 1978. Other finance has been provided to build machine tools for stock. Over the period 1966-78 it may be estimated that the gross sum spent by the British government on the machine tool industry by one scheme or another . . . was about L100 million (Sanders, 1978).

The failure of U.K. machine tool manufacturers to adjust to fluctuations in demand for machines tools, the principal characteristic of the machine tool sector worldwide, the subsequent build-up of delivery backlogs and the technological advances of foreign (Japanese, German, U.S.) machine tools are the major reasons for the significant rise in machine tool imports into the U.K. in the 1980's (Heim, 1984).

The British government has over time undertaken a series of policies to support indirectly the native machine tool industry in Britain via a number of support mechanisms including financial aid for investment, restructuring, modernization, assistance for research and innovation, technical advice, information and export credit services (Sanders, 1978). None of these policies has been directed explicitly at the machine tool sector. Since 1975, when the British government provided \$54 million in aid specifically to the U.K. machine tool industry to foster production improvement and higher technology content in its products, the British government has not implemented any programme solely aimed at supporting machine tool producers. The U.K. machine tools

industry since 1975 has received only indirect assistance from the British government's overall industrial support programmes. Several of these may have benefitted U.K. machine tool makers and robotics manufacturers (Sanders, 1978; Pavitt, 1980).

For example, the government programme to support innovation and promote the development and application of numerical control (NC) machines and flexible manufacturing systems (FMS), have been of assistance to the domestic machine tool industry.⁽⁴⁾ In fact, several U.K. machine tool manufacturers have participated in a number of FMS projects funded for the most part by the British government. Some of these have been relatively large. As of 1987, the DOI had committed over \$60 million for the development and installation of FMS by U.K. industrial firms, and \$50 million has been allocated to high-risk FMS projects under the U.K. Science and Technology Act (DOD, 1987).

The DTI support programme for information technology represents an indirect British government programme relevant to machine tool technology, but one which the machine tool sector in the U.K. has used to advance the technology base of U.K. machine tools. During the 1976 to 1987 period the DTI allocated over \$300 million annually for the above programme in its budget (DOD, 1987).

Another British government programme that indirectly benefits the machine tool industry in the U.K. is the "Small Engineering Firms Investment Scheme" which assists British firms in the purchase of technologically advanced machinery and equipment. Approximately \$150 million per annum was provided to British firms under this programme between 1983 and 1987 (ITC, 1986).

The Thatcher government since 1981 has given priority status to programmes aimed at increasing the efficiency of the U.K.'s manufacturing industries and, hence, promoting machine tool and robotics development, application, and production. Financial assistance has been provided for both machine tool and robot producers and users, mainly under the Robot Support Programme, a subset of the Support for Innovation Scheme (SFI) launched in 1982 by the DTI (ITC, 1986).

Within the SFI scheme, government assistance to promote the development and diffusion of robots was provided under the Robot Support Programme (RSP). The RSP provided three principal areas of government assistance:

- a) Companies are eligible to receive free initial advice through the Ministry of Industry concerning the application of robotics to their production or processing operations. In the affirmative, companies can employ independent consultants to carry out technical and economic appraisal, and feasibility studies for which the government will provide up to 15 man-days of consultancy time at 50 percent of normal cost.

- b) Companies developing new industrial robots and peripheral equipment can receive up to 25 percent of eligible costs in government financial assistance. Eligible costs include costs incurred from the initial design stage to the point of actual commercial production.
- c) Companies are also eligible to receive financial assistance for the installation of robots, i.e., up to 33 percent of the costs of new processes that feature robots as primary constituents. These costs include capital cost and development time cost to get the robot installation working efficiently (ITC, 1986).

In a concerted effort to increase the productivity of its industries, the British Government has also instituted several programmes of support and incentives to promote directly the development and use of the most advanced machine tools-- industrial robots. The Science Research Council provided \$59 million in 1982 for industrial robot "awareness and demonstration" in the U.K. Under the Product and Process Development Schemes, British government grants were given for up to 50 percent of the cost of robot design and development to British firms, and up to 25 percent of the cost of projects involving design and development by U.K. manufacturers of new industrial robots and associated equipment (ITC, 1986).

There are other forms of government assistance that have directly or indirectly benefitted the British robotics industry. As a means of providing investment incentives for all British

companies, including robot producers and users, the British government has granted tax relief for capital expenditures on plants and machinery (deCarmoy, 1978). The tax allowance against corporate taxation applies to 100 percent of the cost of equipment and machinery purchased or used in the U.K. and up to 10 percent of the cost for equipment leased to overseas entities (ITC, 1983; ITC, 1986).

The unique feature of machine tool and robotics research and development in the U.K. is that it is driven to a large extent by engineering and application thrusts, rather than by the scientific issues as in the U.S. and Japan. This is due primarily to the nature of government funding programmes which are directed towards a push for immediate modernization of the U.K.'s industry (Daly, et al., 1985).

Three British universities are especially active in the research of advanced machine tools and robotics application: Edinburgh, Warwick and Oxford. The research effort at the University of Edinburgh has concentrated on studying the kinematics and geometry of industrial assembly operations, as well as the development of robot language. At Warwick University the research effort has concentrated on mobile robot application. The research at Oxford university is also application-oriented and focused on automating factory processes such as arc welding.

The British government is funding most of the research efforts at these three universities.

10.5.3 The United Kingdom Government's Policies for the Development of Advanced Materials

The U.K. government, prior to 1970, supported the advanced ceramics industry with significant funding. A number of research and development projects in advanced ceramics were undertaken in universities, and in industry. Most of this effort ceased in the mid-1970's.

There are some research and development efforts currently being undertaken by British Aerospace in polymers and advanced composites. Most of this effort is funded by the MOD and information on these activities is not available.

10.6 CONCLUSIONS

The industry policies of the British government have, for the most part, been consistent with the "accepted" norm of the free market system. The British government has adopted policies for the benefit of the industrial sector as a whole, rather than implemented specific sectoral policies. The principal policies by have been those of assistance to research and development

activities, education (including education of industrial managers in the adoption of advanced technologies) and training.

The one area where British government policies have been somewhat unique is in the encouragement of mergers for some British firms. The fundamental reason for this policy of encouraging rationalization in some sectors is the relatively limited domestic market for some U.K. industrial products. Prior to World War II the very extensive U.K. "interests" in colonies assured U.K. firms of a large overseas market for most of the products manufactured. Geopolitical changes after World War II closed many, if not most, of these offshore markets to U.K. firms. The very rapid growth of the Japanese export markets further reduced the declining export potential for U.K. goods.

Unlike the Japanese government, which essentially closed its domestic markets to foreign goods until such time as the Japanese manufacturers had achieved economies of scale in their production, British government policies have allowed for essentially unrestricted imports. This in turn has reduced domestic markets for some U.K. products. The fact that some of the imported products embodied advanced technologies reduced both domestic and overseas markets for U.K. firms even further.

Under such conditions, U.K. policies to combine the many small firms in certain sectors of the economy (i.e., motor

vehicle manufacturers, machine tool markets, electronics) into fewer and larger enterprises, have been reasonable and necessary.

These rationalization schemes, however, did not bring about a revitalization of the U.K. industrial sectors because U.K. products had not kept pace with the technological advancement embodied in products offered by foreign competitors.

Scientific activities and advancement in the U.K. have resulted in a large number of important scientific discoveries. The universities in the U.K., research institutes and even private sector entities have executed outstanding work in the basic sciences. In the past, the applied research effort in the U.K., unfortunately, has not been emphasized. Consequently, the most recent policies of the government have placed priority on applied research and development.

Support for this statement is not difficult to find. Witness, for example, the recent ABRC plea and the emphasis placed on the need to apply scientific findings to the development of marketable products (emphasis added), to the necessity to select scientific activities which are "strategic", i.e., lead to industrial innovations. The British government's "White Paper" of 1987 which expressed the need to establish "collective Ministerial consideration under the Prime Minister's leadership of science and

technology priorities" (emphasis added) points out also the need for applied research in the U.K.

The historic lack of emphasis on applied research or industrial innovation by the U.K. scientific community has not only reduced the growth of advanced technology sectors in the U.K., but has also retarded the adaptation of advanced technologies by manufacturing firms in the U.K. in their production processes.

For example, the very advanced microprocessor developed by the U.K. firm Inmos, the so-called "transputer", has had a very limited market in the U.K. because many industrial enterprises did not possess process machinery sufficiently advanced to utilize this microelectronic device. Also as reported by Daly, Hitchens and Wagner (1985), the results of Census of Production in the post-World War II period indicate that the U.K.'s industrial output has been about one-half of that in Germany and below that in most other E.C. nations. The authors attribute this poor U.K. performance, at least partly, to the older vintage technology used in U.K. manufacturing establishments.

The outcome of this past emphasis has been the older technology content of U.K. products as compared to the products of other nations. This, in turn, has further limited markets to U.K. goods, both domestic and international.

Unlike the French or Japanese governments, the British government has not (except for the Alvey Programme) used the vehicle of very large, very focused, government funded projects to improve the technology adaptation in the industrial sector or projects. In the light of France's very poor experience with such projects, the British government's decision may be correct. Industrial firms in the U.K., with the apparent approval of the British government, have selected another path to increase their market share for their projects, that of merging, purchasing or otherwise acquiring those foreign firms which possess both the desired advanced technologies and the access to markets in the U.K. and abroad. Often such strategies have proved highly effective. In addition, such transactions by U.K. firms have enabled them to reduce their dependency on a single market such as defence-related products. However experience in the U.S. of such transactions shows that these reduce (perhaps only temporarily) a firm's ability to plan and execute the required research and development activities.

There exist a number of factors which may impact on the future of British advanced technology industries in the U.K. The recent science and technology policies of the Thatcher government have attempted to address most of these. Others are either based on historical trends and therefore not amenable to immediate adjustment by any government policy or lie in the future. The

establishment of the European Common Market in 1992 is certainly one of the latter.

FOOTNOTES TO CHAPTER 10

- 1) An aspect of U.K. society that has important implications for the conduct of research is the relatively low degree of job mobility. With deep psychological and economic roots, the tradition of "staying put" cuts across all of U.K. society, and for that matter, most European societies as well. For the labour force as a whole, it is estimated that about 10 percent of Europeans change jobs as often as once a year as contrasted with the 30 percent in the U.S. who did so in 1981. Among UK "professionals" in all fields, job changes are relatively rare. Whether in academia, government or the private sector, their employment is effectively tenured; this situation has been reinforced by such factors as non-portable pension schemes and housing problems. It should also be noted that mobility among university students is very limited. Once embarked on a particular curriculum they cannot, in practice, readily change either curriculum or educational institution without starting again from the beginning. The great exception to the above points, emigration.
- 2) The U.S. Department of Defense has selected the Centre for Exploitation of Science and Technology as a potential recipient of research and development funds for defence-related activities.

- 3) British government policies with regard to the micro-electronic sector received considerable encouragement from U.S. microelectronic firms operating in the U.K.
- 4) Some U.K. machine tool firms have received funding for advanced machine tool purchases from the U.S. Department of Defense in order to facilitate manufacture of defence-related equipment produced jointly with U.S. firms.

CHAPTER 11:

SCIENCE AND TECHNOLOGY POLICIES
IN THE UNITED STATES

11.1 INTRODUCTION

Since 1982 the economy of the U.S. has experienced a period of exceptional growth and expansion, with increasing production of goods and services, increasing wages and salaries and increasing GNP, which for 1988 was estimated at \$3750 billion (in constant 1982 dollars).

The U.S. economy does have a number of problems, however. In particular, over the last decade the U.S. has lost significant segments of its comparative advantage in a number of industry sectors, especially advanced technology sectors (Kennedy, 1987).

A brief restatement of the data on changes in the U.S. export shares from 1955 to 1987 will provide ample evidence for this. In 1955 exports of all manufactured products represented about 26 percent of the total world export shares; by 1988, the U.S. share had declined to less than 13 percent. In advanced technology product exports, the U.S.' share in 1955 was about 36 percent of the world total; by 1988 this share had declined to less than 18 percent. Statistics for U.S. international trade since 1972 show negative trade balances for automobiles, consumer electronics, steel, and textiles. Since 1980 the U.S. has had rapidly growing

negative trade balances in microelectronics, machine tools, metalworking machinery, computers, and electrical machinery. Indeed the current account trade balance for the U.S. has shown an almost continuous decline since 1980, estimated to reach about \$150 billion by 1990.

This rapidly worsening trade deficit results from a number of factors, some of which are exceptionally difficult to correct by private sector or government policies. The most difficult of these pertain to the industry practices performed by private sector firms in the U.S. (Landau and Rosenberg, 1986).

These are discussed in comprehensive detail in a 1989 study by the Massachusetts Institute of Technology entitled Made in America: Regaining the Production Edge (Gertouzos, et al., 1989). This massive research effort by one of the premier academic institutions in the U.S. reports the following on U.S. industry practices:

The industry studies revealed two types of outdated strategies that are impeding industrial progress today: an overemphasis on mass production of standard commodity goods and an economic and technological parochialism. Both are holdovers from the unique economic environment that prevailed after World War II. For decades after the war U.S. industry was able to flourish by mass-producing undifferentiated goods principally for its own markets, which were large, unified and familiar. Because firms in most other countries had to rebuild in economies devastated by the war, they could mount no significant competition and were largely ignored by U.S. industry.

Not only did U.S. producers sell their wares primarily to the domestic market, they also drew their technical expertise almost exclusively from U.S. factories and laboratories. Such technological parochialism blinded Americans to the growing strength of scientific and technological innovation abroad and hence to the possibility of adapting foreign discoveries. In the 1950's and 1960's for example, American steel producers lagged behind Japanese and European steelmakers in adopting such new process technologies as the basic oxygen furnace; later they were again slow to adopt continuous casters and such quality-enhancing technologies as vacuum degassing and oxygen injection. The critical error in many of these cases was the failure to recognize the worth of someone else's innovation.

One should not conclude that the state of industry in the U.S. or of the advanced products industry is declining rapidly. It is not, and some industry sectors in the U.S. have shown exceptional growth (Landau, 1988). It would also be unreasonable to conclude that the policy makers in the U.S. do not recognize the extreme importance of scientific, research and development activities which are the basis for industrial growth and advance. The benefits of scientific activity are fully recognized by the U.S. government (Mansfield, 1988; Baumal, 1989).

"Not only is basic research an essential investment in the nation's long-term welfare, but it is largely a federal responsibility because its benefits are so broadly distributed. Quite simply, basic research is a vital underpinning for our national well-being" (Keyworth, 1984). This statement by George A. Keyworth, II, the Science Advisor to President Reagan made in 1984, summarizes the U.S. federal government's rationale for

enacting policies, admittedly limited in scope, for the advancement of science and technology in the U.S. A review of other U.S. government policy statements, budget documents, testimonies of federal government officials and other statements indicates some intervention by the U. S. government in areas generally considered to be the responsibility of the private sector. U.S. government interventions have, however, been limited and those which have taken place have been defended on several grounds.

The first of these is cultural in origin and assumes that scientific knowledge is an intrinsic public good, which benefits society in general and the U.S. population in particular. The U.S. government therefore has an obligation to advance scientific knowledge (Bailey and Chakrabarti, 1985).

The second is that research and related activities promote national and economic security and economic growth in the U.S. It is assumed by public servants in the U.S. that advances in technology result in improvements to the U.S. national defence posture and in the improvement of U.S. competitiveness in the world's markets. Increased U.S. competitiveness relative to other nations improves the economic well-being of the U.S. population. Underlying this assumption is the belief held by the U.S. government and supported by economic theories that private industry in the United States (as well as elsewhere) will underinvest in scientific research and related activities because of the high-

risk, non-captivability of returns on such investments. The U.S. government therefore has the responsibility of correcting under-investment and of either funding scientific research activities or encouraging funding by the private sector via appropriate public policies (Boretsky, 1982; Tirman, 1984; Clark and Malalane, 1988). In practice, such policies are presented in the form of tax incentives and the reduction of disincentives to research, rather than direct government funding, except for a relatively large number of scientific and research activities directly related to national security.

The third justification for government intervention is socio-political and emphasises the highly desirable effects of sciences and related activities on public health, safety, environmental quality, availability of resources and other areas (Habakkuk, 1962). These three guiding principles are well summarized by the President's Science Advisor: ". . . strong support for basic research permits U.S. scientists and engineers to challenge intellectual frontiers in the most important fields of science and technology. That provides the new knowledge that drives our economic growth, improves our quality of life, and underlies our national defense" (Keyworth, 1984).⁽¹⁾

In contrast to other industrialized nations such as Japan, Germany or the U.K., U.S. science policy is very fragmented and decentralized among complementary and competing interests. This

results in science and technology policies enacted by the U.S. government that may be described as pluralistic or chaotic, depending on the point of view of the observer.

Many observers agree, however, that deficiencies in the U.S. national science policies indeed exist and that these derive from the absence of a single science policymaking body in the U.S. (Golden, 1988). In most other nations, a mechanism to prioritize, guide and administer science policy exists in some form or another. Although the Office of the Science and Technology Policy (OSTP), headed by the President's Science Advisor and located in the Executive Office of the President, is charged with providing advice to the President and, to some degree, direction on science policy, its functions are limited in theory and, at times, non-existent in practice.

This fragmentation of the science policy structure in the U.S. does not result in a comprehensive science policy enactment and the appropriate allocation of public monies for scientific and related activities or for basic as opposed to applied research. The "mission agencies" which receive most of the public monies for science and technology activities demand funding for projects which are applied and have immediate practical applications. The funding of basic research activities is not often undertaken by these "mission agencies." The activities which may be classified as basic science in the U.S. are designated for the academic

institutions. However, because U.S. institutions of higher learning also undertake contract research for U.S. mission agencies, basic research activities may again be postponed in favour of applied projects.

The creation of a U.S. Department of Science, which would serve as a central science policy agency for the U.S. government, has been proposed from time to time since the Truman Administration in the late 1940's. In the most recent proposal of this concept, developed by the U.S. President's Commission on Industrial Competitiveness in 1987, a Cabinet-level Department of Science and Technology was to be created to administer U.S. government non-military research activities and provide a central science voice. "Such a department would transform the current, fragmented formulation of policies for science and technology into one that would be far more effective in meeting long-term national goals" (Commission, 1988).

This latest proposal, like similar attempts in the past, has been controversial. Some well recognized members of the U.S. scientific community have been less than enthusiastic about such a "Science Department" in the U.S. government. Joshua Lederman, Director of the Fermi National Laboratory, for example, has stated that such a department would be a mistake, because it would be dependent on a single personality, and if not administered well, would result in a reduction in U.S. government funds for science.

Other members of the U.S. scientific community have been even more strongly opposed to such a Department. James Carey, Executive Officer of the American Association for the Advancement of Science has described the proposal as "an extremely bad idea" and has contended that the present pluralistic arrangement in the U.S. has been highly successful for the support of the research and development activities in the U.S.

Long term research projects are rejected by U.S. industry sectors. The cardinal criterion for selecting and undertaking research activity by U.S. private sector firms is that the results of such activity have a measurable and immediate impact on the financial balance sheet of the enterprise undertaking such an activity (Bergsten, 1980; Tatom, 1986). In the U.S. the balance sheet for all private enterprises appear on a quarterly basis, and are referred to as "quarterly reports." The importance of these "quarterly reports" on the management of U.S. industrial firms cannot be overemphasized, because these are used to determine the prices of the firms' stocks and bonds and to a considerable degree determine the performance rating of industry executives. Under such conditions there are few U.S. industry executives who are willing to risk public criticism of their management skills, provided on a quarterly basis, for the sake of improving a firm's financial performance, sales and income at some future date (Nelson, 1982).

However, the highly decentralized structure of the science policy leadership in the U.S. allows for flexibility and responsiveness to research opportunities. Further, advocacy and guidance for scientific and related activities in the U.S. are provided by several highly prestigious scientific associations such as the National Academy of Sciences (NAS) and the American Association for the Advancement of Science. In the U.S. scientists also play an important role in decision making in all science related funding agencies through various advisory and peer review groups. Advisory groups also influence science policies at the level of U.S. Congress, the Executive Office of the President and among U.S. federal government departments and agencies (Hilts, 1988).

Attempts to influence the direction of the scientific and research activities of industry have increased, as a result of the declining technological status of U.S. industry and increased competition from abroad.⁽²⁾ Industry sectors have also initiated several innovative approaches to research and development activities. Research projects undertaken jointly by university-industry groups is one such innovation. Another is the establishment of joint research ventures between private firms, until recently prohibited by antitrust regulations in the U.S. With the passage of the National Cooperative Research Act of 1984, the number of joint research ventures between U.S. industrial firms has increased at a very rapid rate.

The U.S.' science and research structure contains several other unique features, which do not exist to the same extent in other nations. One of these is the presence of large numbers of independent non-profit and commercial laboratories, technical establishments, and research organizations which undertake research and related activities. Another is that many, if not most, of the larger U.S. manufacturing firms have established significant research and development entities. These not only conduct research and development activities related to the mission of the parent firm, but also undertake significant contract research. Finally the U.S. DOD is a very important client for scientific, research and development activities in the U.S. Such activities are undertaken by all types of research establishments including industrial firms, non-profit research laboratories, commercial testing facilities, academia and others (Tirman, 1984).

11.2 SCIENCE AND TECHNOLOGY PERFORMERS IN THE UNITED STATES

The dominant characteristic of the U.S. resource pool for the performance of scientific, research and development and engineering activities is that these resources are available to a wide variety of institutions and organizations.

There are at least five types of diversified organizations that perform scientific research and related activities in the

U.S.: a) the federal government; b) industry; c) universities and colleges; d) Federally Funded Research and Development Centers (FFRDCs); and e) other non-profit institutions.

The meaning of these five categories is self-explanatory except for the FFRDCs. FFRDCs (probably the nearest U.S. equivalent to "national laboratories" in France, the U.K., and Germany) are research and development organizations exclusively or substantially financed by the U.S. federal government in order either to meet a particular objective of a government directed project or to provide facilities and equipment at certain U.S. universities for research and training purposes. The administrative structure of FFRDC's varies. Some FFRDCs are administered by private industrial firms, others by universities, and some by non-profit institutions.

11.2.1 Universities and Colleges

Universities are the predominant performers of basic research in the U.S. and contribute significantly to applied research and development efforts. Universities and colleges account for almost half of the total U.S. basic research effort. Almost all such research is conducted by about 170 doctorate granting institutions in the U.S., of which 35 percent are privately controlled.

In most U.S. universities, a decentralized structure prevails, with authority for decisions resting with university departments rather than with central administrations. The university system in the U.S. allows for diversity in the conduct of research, as emphasized in a recent report by the U.S. National Research Council, "The university, through its reward system and the freedom it provides, allows its faculty to conduct research in ways that are difficult to replicate outside of academia. The criteria for promotion in academia emphasize creativity, novelty, and widespread dissemination of research findings" (NRC, 1986).

Since the mid-1970s, university-performed research in the U.S. has included at a growing rate, large scale research projects conducted through organized university research centres. Many of these centres are funded by the DOE (in nuclear sciences) and the DOD.

Table 11.1 presents a percentage breakdown of research and development expenditures at U.S. universities by source of funding for 1987. Over half (55 percent) of total university research and development is devoted to the life sciences, specifically the biological and medical sciences. Other fields of concentration include: engineering, which accounts for 14 percent of the total; physical sciences, 11 percent; and environmental sciences, 7 percent. A relatively small number of universities receive a dispro-

TABLE 11.1

R&D Expenditures at Universities and Colleges,
by Source of Funds, Character of Work, and
Science/Engineering Field: United States, 1987

<u>Source, Character, and Field</u>	<u>Percent of Total</u>
Source of Funds:	100.0
Federal Government	65.4
State and Local Government	8.1
Industry	4.5
Institutional Funds	15.1
All Other Sources	6.9
Character of Work:	100.0
Basic Research	66.8
Applied Research and Development	33.2
Field:	100.0
Engineering	14.1
Physical Sciences	11.3
Environmental Sciences	7.7
Mathematical/Computer Sciences	3.4
Life Sciences	54.7
Other Sciences	8.8

Source: National Science Foundation, "National
Patterns of Science and Technology Resources
1988," NSF 84-311, 1988.

portionate share of the federal government support and therefore account for a large percentage of the research performed, with about 25 percent of total federal government support for universities received by about ten universities. The concentration of performance is even more apparent when the ranking of the U.S. universities is taken into account. The top 50 universities accounted for about 64 percent of all government research and development funding provided to academic institutions.

11.2.2 Federally Funded Research and Development Centers

FFRDCs are performers of research and development activities for which the primary source of support is the U.S. federal government. FFRDC's are established either to meet a particular scientific or research objective often associated with a specific large scale project, or to provide major facilities for research purposes. Individual Centres may be administered by a university, an industrial firm or a non-profit institution.

FFRDCs can be differentiated into four types: a) research laboratories, b) R&D laboratories, c) study and analysis centres, and d) system engineering/system integration centres:

- a) Research laboratories are principally used for the pursuit of research (as distinguished from development). Most concentrate on basic research in one particular area and many provide major, unique, research facilities for national use. There are ten such laboratories in the U.S.;
- b) R&D laboratories engage in various facets of the R&D process. Most are multiprogramme laboratories active in a variety of science and/or engineering areas, though some specialize in a broad functional area such as national security or nuclear energy. Most of these institutions contain major national research and/or testing facilities. There are twenty such laboratories;
- c) Study and analysis centres are involved exclusively in analytical activities -- no hardware-related laboratory research or development is carried out. There three such centres in the U.S.; and
- d) System engineering/system integration centres primarily provide systems engineering, R&D system integration, and management support for definition and development of large technical systems. There are two system engineering/system integration centres (Tirman, 1984).

A list of the principal FFRDCs categorized as defined above is shown in Table 11.2. Together, these U.S. FFRDCs expended about \$3 billion in 1987.

11.2.3 In-House U.S. Government Research and Development Facilities

Research and development and related activities performed by the federal government in its own facilities (excluding FFRDCs) accounts for about 15 percent of the total national basic research

TABLE 11.2

FFRDCs by Categories by Sponsor and Funding, 1987

Research Laboratories

Department of Energy sponsored:

- a) Fermi National Accelerator Laboratory (Universities Research Association, Inc.), Batavia, Illinois (\$139.8 million); and
- b) Stanford Linear Accelerator Center (Stanford University), Stanford, California (\$71.2 million).

National Science Foundation sponsored:

- a) Cerro Tololo Inter-American Observatory (Association of Universities for Research in Astronomy, Inc.), La Serena, Chile (\$6 million);
- b) Kitt Peak National Observatory (Association of Universities for Research in Astronomy, Inc.), Tucson, Arizona (\$11.2 million);
- c) National Astronomy and Ionosphere Center (Cornell University), Arecibo, Puerto Rico (\$5.3 million);
- d) National Center for Atmospheric Research (University Corporation for Atmospheric Research), Boulder, Colorado (\$32.5 million);
- e) National Radio Astronomy Observatory (Associated Universities, Inc.), Green Bank, West Virginia (\$15.1 million); and
- f) Sacramento Peak Observatory (Association of Universities for Research in Astronomy, Inc.), Sunspot, New Mexico (\$2 million).

R&D Laboratories

Department of Defense/Air Force sponsored:

- a) Lincoln Laboratory (Massachusetts Institute of Technology), Lexington, Massachusetts (\$155.1 million).

Table 11.2 (continued)

Department of Energy sponsored:

- a) Ames Laboratory (Iowa State University of Science and Technology), Ames, Iowa (\$15.5 million);
- b) Argonne National Laboratory (University of Chicago and Argonne Universities Assn.), Argonne, Illinois (\$223.9 million);
- c) Brookhaven National Laboratory (Associated Universities, Inc.), Upton, Long Island, New York (\$164.4 million);
- d) E.O. Lawrence Berkeley Laboratory (University of California), Berkeley, California (\$130.7 million);
- e) E.O. Lawrence Livermore National Laboratory (University of California), Livermore, California (\$590.3 million);
- f) Los Alamos National Laboratory (University of California), Los Alamos, New Mexico (\$490.2 million);
- g) Oak Ridge Associated Universities, Oak Ridge, Tennessee (\$9.3 million); and
- h) Princeton Plasma Physics Laboratory (Princeton University), Princeton, New Jersey (\$125.3 million).

National Aeronautics and Space Administration sponsored:

- a) Jet Propulsion Laboratory (California Institute of Technology), Pasadena, California (\$208.5 million).

Study and Analysis Center

Department of Defense/Navy sponsored:

- a) Center for Naval Analyses (University of Rochester), Arlington, Virginia (\$21.9 million).

Source: National Science Foundation, "Federal Funds for Research and Development Fiscal Years, 1987," NSF 87-319.

effort and for about 36 percent of the research and development effort in the U.S.

The U.S. federal government agencies which are the principal performers of these activities are the so-called "mission-agencies," whose research and related work is carried out directly by their own personnel, i.e., public servants in these facilities. The principal U.S. "mission agencies" are the U.S. Departments of Agriculture, Defense, Energy, and Health and Human Services, as well as the National Aeronautics and Space Administration (NASA).

Four U.S. government agencies, the National Science Foundation (NSF), the DOD, the DOE, and NASA undertake significant research and development efforts in advanced technology areas.

11.2.4 National Science Foundation

The NSF has been categorized as the U.S. equivalent of a central science agency in other industrialized nations. The NSF provides about 18 percent of all U.S. federal government support for basic research and 13 percent for all research and development undertaken in the U.S. Unlike the central science agencies in other industrial nations, the NSF does not establish a national science policy for the U.S., nor is it required to follow the recommendations of the President's Science Advisor. The areas of science, research, development and engineering, that are funded by

the NSF reflect the opinions expressed by the U.S. scientific establishment, such as major academic institutions, the NAS, the American Association for the Advancement of Science (AAAS), research institutes and scientists employed by various U.S. federal government agencies.

The NSF, in its present format, was established in 1954 to support primarily basic research in all disciplines through grants to scientists. In the last twenty years the NSF has funded an increasing proportion of applied research. Concepts for scientific, research and related activities are generated by individual scientists and submitted to the NSF as unsolicited proposals. These are reviewed through an external, elaborate, but not always satisfactory, peer advisory system, with final evaluation and determination for funding made by the NSF staff.

The fields of science funded by the NSF in 1987 included: physical sciences (30 percent); environmental sciences (24 percent); life sciences (18 percent); engineering (15 percent); and mathematics/computer sciences (8 percent).

11.2.5 Department of Defense

The U.S. DOD provides 13 percent of all federal government support for basic research and approximately 33 percent for all research and development in the U.S. The DOD's support of

research activities is based on specific objectives that are largely directed toward the development of defence-related products.

About 48 percent of all DOD basic research funds are allocated to U.S. universities and colleges (including FFRDCs), with 30 percent of these funds allocated for engineering activities.

11.2.6 Department of Energy

About 17 percent of all U.S. federal government support of research and development is provided by the U.S. DOE. DOE support frequently, but not always, takes the form of large block funding to the various FFRDCs. About 85 percent of DOE research funds support research in the physical sciences, with 75 percent supporting research in physics, and 10 percent devoted to engineering research.

11.2.7 National Aeronautics and Space Administration

NASA accounts for 10 percent of total U.S. federal government basic research funds, and 15 percent of all research and development funding. NASA conducts over half (53 percent) of its basic research internally, and, as a typical mission agency, the majority of NASA's extramural funding is for specifically targeted projects that complement its intramural efforts.

Over half of NASA's support to research is for the physical sciences, with about 30 percent devoted to engineering. Most of the research activities consist of research in fundamental aeronautical disciplines such as fluid and thermal physics, materials and structures, and propulsion.

11.2.8 Industry Sector Laboratories

The U.S. industrial sector includes research and related activities undertaken by both manufacturing and nonmanufacturing firms in the U.S.

The breakdown of industrial performance of research activities by field of science in 1987 was as follows: physical sciences (40 percent); engineering (25 percent); life sciences (15 percent); mathematics (1.6 percent); and environmental sciences (1.4 percent).

11.2.9 Independent Non-profit Research Institutions

The research and development effort of the U.S. non-profit research institutions is fairly equally divided among basic research, applied research and development. There are considerable variations in management structures, sources of funds and types of research undertaken by the U.S. non-profit research institutions. Some of the U.S. non-profit institutions are

substantially endowed or supported by foundations, and resemble universities in their research activities. Others are engaged primarily in contract research, and resemble other private profit-making research enterprises.

11.3 U.S. FEDERAL GOVERNMENT'S SCIENCE AND TECHNOLOGY POLICIES

The U.S. government does not exercise science and technology policies to the same extent as do, for example, the French or Japanese governments. There do exist, however, at any one time in the U.S. a set of informal science and technology goals that implicitly determine priorities of science and technology activities and implicitly allocate support for these activities. Official intervention by the U.S. government in the free market mechanisms, however, has taken place from time to time. As stated by Vernon (1989, 1989):

Not that the United States has been altogether lacking in such policies. The Department of Defense, operating under the exceptional license that goes with "national security" programs, has promoted one industrial sector or another through its investments in research or through procurement contracts. The agricultural research and farm extension policies of the United States have been among the broadest in the world. The U.S. government also has helped to fend off bankruptcy for Chrysler and Lockheed, by providing those companies with financial support that has kept them in operation. U.S. savings and loan associations have been the object of extensive government support programs. And most recently, the U.S. government has promoted a joint effort of the semiconductor industry to enhance its research on the production of chips.

These cases, however, have not added up to a national policy. They have covered only small patches of the American economy and have usually been labeled as exceptional measures, responsive to extraordinary circumstances or outright crises.

There are other examples of explicit policies enacted by the U.S. government to advance technology or industry sectors. The U.S. government has subsidized the development of the nuclear power industry for many years. In the mid-1970's, the U.S. government provided funding for extracting oil from shale and sand. The U.S. tax system is far from neutral. The U.S. has had tax credits for research and development for new investment in equipment, and for the use of new energy technologies. Exports have received favourable treatment under the Export-Import Bank whose loans have subsidized U.S. exports of commercial aircraft and electric generating equipment. The rules on accelerated depreciation favour certain types of investments over others (U.S. Congress, 1982). However, these tax measures have rarely been part of U.S. government targeting of specific civilian industries. U.S. subsidies, explicit and implicit, have generally encouraged a broad range of activities and have seldom been coordinated with other efforts to develop a specific advanced technology industry (SHC, 1986).

The same can be said about expenditures by the U.S. government's departments and agencies on various research and development efforts. The total annual budget of the U.S. government for science, research and development has averaged over the last

decade or so some \$103 billion (in 1982 dollars) as compared to \$35 billion in Japan; \$19 billion in Germany; \$14 billion in France and \$12 billion in the U.K. The U.S. government funds approximately one-half of the expenditure for science and related activities. U.S. government funds designated for science and technology activities are dispersed among many U.S. government agencies and therefore may impact on many industry sectors.

Since 1982, the DOD share of the U.S. government's science and technology funds has significantly increased to about 65 percent of all federal government research and development expenditures. Other U.S. agencies of importance include the DOE, 9 percent -- more than half of which serves defence objectives; the National Institute of Health, 9 percent, NASA, 7 percent; the NSF, 3 percent; and the Department of Agriculture, 2 percent. Four government agencies: the NIH, the NSF, the DOD and the DOE, account for about 85 percent of the total U.S. federal government support of academic research and development. Three agencies: the DOD, NASA, and the DOE, account for over 95 percent of federal government support for industrial research and development.

It must be noted that the magnitude of the U.S. government funds allocated to research and development is very large when compared to research and development budgets in the U.K., France or Germany. Even the relatively small (by U.S. standards) expenditures of single U.S. departments, such as the Defense

Advanced Research Projects Agency (DARPA), are larger than the total research development and related funds provided by the German government for its electronics sector.

In broad terms, however, the U.S. government has not enacted science policies of the type used by the French or Japanese governments. Aside from DOD procurement, the U.S. has not generally used the industrial policies employed by other nations. Except for restrictions on classified defence work, U.S. markets are open to imports of foreign advanced technology goods or investments by foreign firms. There have been no attempts by the government to subsidize loans for specific industries, to help plan their development, or to provide incentives for investing in specific industry sectors (Gruber, et al., 1967).

Furthermore, the U.S. government has been generous in allowing exports of U.S. technology abroad, in terms of intellectual property exports, exports of goods and services and "exports" of U.S. owned manufacturing facilities (Dreameer, 1976; Gruber and Vernon, 1970). With regard to this latter category, such "exports" are not insignificant. In the 1980's U.S. firms expended on average about \$40 billion per annum for the construction of manufacturing plants in foreign nations, approximately 8 percent of the total annual value of industrial facility construction in the U.S.

The relative decline of advanced technology sectors since 1980 and the large and increasing trade deficit in manufactured products have prompted a number of members of the U.S. science establishment to call for an inquiry into the need for a U.S. science and technology policy (Hanger, et al., 1986). Few of these, however, recommended that a U.S. government directed science and technology policy be established. For example, the prestigious National Academy of Engineering in a recently issued and widely publicized statement, suggested that the U.S. government should improve technology advancement and bolster U.S. competitiveness by enacting the following policies:

- a) Reducing capital costs through policies and incentives for increasing the national savings rate and encouraging long-term investments in plans, equipment, and research and development;
- b) Revitalizing the White House Office of Science and Technology Policy or increasing the responsibilities of the Under Secretary for Technology in the Department of Commerce as a move toward coupling technology policy with economic and regulatory policymaking;
- c) Improving engineering education at pre- and post-college levels and strengthening science, mathematics, and technical education; and
- d) Supporting the civilian technology base in addition to the science base in order to bolster advances in generic technology (NAE, 1988).

The U.S. House Committee on Science, Space, and Technology, established a Task Force in 1988 to investigate the role of the federal government in science, technology and industry policies.

In several reports published by this Task Force the following proposals were made.

A new U.S. government office.

Reflecting general dissatisfaction with the current arrangements for establishing technology policy, the Task Force recommended the establishment of a new organization to advise the President and Congress on federal research and development priorities. The exact nature of such an entity was not spelt out, but the Task Force considered arrangements ranging from a new Department of Science and Technology to an expanded Office of Science and Technology Policy.

Support for consumer electronics.

Because the consumer electronics industry "has essentially been surrendered to the Japanese," (Task Force, 1988) a bold initiative was recommended by the Task Force. It recommended the establishment of a National Advanced Technology Center for Consumer Electronics that would work with the private sector on joint development projects.

One agency of the U.S. Government -- the DARPA operating under the DOD has, since 1983, actually supported selected U.S. industry sectors by funding office projects which have considerable applications in the civilian economy. This effort by the

DARPA, which has not received the blessing of all other interested parties, includes the following five projects:

- a) Sematech, Budget: \$100 million.
Objective: Semiconductor industry consortium designed to restore the ability of U.S. companies to compete with the Japanese;
- b) High-Definition Television, Budget: \$30 million.
Objective: Technology for high resolution television displays, for use in consumer electronics and military applications such as sharper radar displays.
- c) Superconductivity, Budget: \$25 million.
Objective: Techniques for making and using recently discovered materials that lose resistance to electricity at higher temperatures than was possible before;
- d) Neural Networks, Budget: \$33 million.
Objective: Preliminary investigation of new kinds of computers modeled after how the brain is believed to function; and
- e) Mimic, (Microwave and millimeter-wave monolithic integrated circuits) Budget: \$67 million.
Objective: Development of advanced chips made of gallium arsenide for use in sensors and communications systems.

In addition, in 1989 the DARPA began to fund research projects directed at the High Definition Television (HDTV) industry. The role of the U.S. DOD and of the DARPA in taking the lead in these research efforts may appear odd, but it results directly from the absence of any other U.S. government agency to fulfill this function.

The paucity or outright absence of U.S. federal government organizations which could administer research and development activities for industry sectors can be readily seen from developments surrounding SEMATECH, the U.S. government supported semiconductor project.

As reported in an August, 1988 issue of Science:

Ask a Washington insider why the defense budget contains money for SEMATECH, the industrial consortium to revive the U.S. semiconductor industry, and you get a wry smile. "I was one of the movers behind the SEMATECH project," said Clyde Prestowitz, former counsel to the Secretary of Commerce. "I didn't want it in the Pentagon, but there's no other place to go."

"We probably should be funded through the Commerce Department, but they don't have any money," said a SEMATECH spokesman.

Nor did anyone else have the inclination, according to Senator Jeff Bingaman (D-NM). "You have a lot of ideologues in the Administration who object strenuously to the federal government taking a leadership role in something like SEMATECH unless it can be wrapped in the robe of national security," he said.

As the United States continues to take its monthly drubbing from Japan in the statistics of international trade, Congress seems more and more willing to fund R&D projects aimed at strengthening American high-tech

industry. But advocates of such programs are in a quandary about which government agency should administer them. Programs like SEMATECH, the National Center for Manufacturing Sciences, and research on high-temperature superconductors have therefore ended up in the Defense Department more or less by default.

The National Academy of Engineering recommended that the federal government focus its efforts to encourage the development of critical technology "through a designated agency," but failed to agree on which agency should do the job.

William Howard, a senior fellow at the academy, ticked off the list of rejected options: The National Science Foundation would "not be appropriate;" the Department of Commerce "essentially has walked away from the job;" the Defense Department "is preoccupied with other motives." The panel eventually settled on the White House Office of Science and Technology Policy as the best of bad options (Daniel, 1988).

The entry of the DOD and the DARPA into the funding of civilian sector research and development projects has received some encouragement from U.S. industry representatives, but the overall reaction to this by U.S. government executives, academia and private industry has been hostile. Charles Barfield, the Director of Science and Technology Policy Studies of the American Enterprise Institute, a conservative research organization with close links to the Bush administration writes:

Sematech and the Darpa HDTV involvement represent an ominous trend, and a perversion of the Defense Department's highly successful role since 1945 as a public Godfather to the U.S. science and technology enterprise.

The extraordinary success of the science-military partnership was based on two characteristics of Defense Department patronage: 1) Key Defense Department science agencies emerged as the most imaginative, farsighted and flexible instruments for basic-science funding in the government; and 2) the department kept a fixed eye on the defense goals of its technology mission and did not

attempt to enter the labyrinth of market economics. Unfortunately, both of these fundamental pillars of the Defense Department science and technology enterprise have been fundamentally altered.

The department's overall funding of basic research as a percentage of total defense funding has declined from 5.2 percent in 1965 to an estimated 2.2 percent in 1990. Further, since 1980, the basic research share of the Darpa budget has decreased by about two-thirds. This means that scientific seed corn for future advanced defense technologies has been persistently underfunded. Further, since basic research ultimately produces substantial payoffs for civilian sectors as well, this underfunding undoubtedly has been detrimental for overall U.S. competitiveness.

In addition, the Defense Department has increasingly expressed support for industrial-policy and technology-commercialization proposals that it has little competence to evaluate and that often merely advance the goals of special interests to raid the public treasury. Over the past few months, Darpa representatives have talked of the necessity for guaranteed markets for HDTV, mandated U.S. production, mandated use of U.S. semiconductor chips and microprocessors in new television equipment, and exclusive licensing to U.S. companies. These policies constitute a dream list for industrial-policy advocates and protectionist special interests, and are at cross purposes with U.S. trade-policy goals to end subsidies, beat back spurious infant-industry arguments and keep markets open for investment.

Before committing scarce public resources and revising regulatory practices for HDTV or any other technology program, the Bush administration should set forth stringent criteria and high thresholds for government intervention (Barfield, 1989).

Similar negative reactions to the DARPA's attempts (or "intrusions" as called by those unfavourable to these activities) to assist U.S. private industry sectors have been expressed by many in the United States. The fact remains that there is no other U.S. government agency which could undertake the lead role

in the administration of such research projects. A similar situation exists in the White House, where the final authority for any and all science policies rests. At the present time the principal Presidential Advisor on U.S. science policy is the Special Assistant for Science and Technology who directs the White House Office of Science and Technology Policy (OSTP).

A brief summary of the past roles of the Presidential Science Advisor, the key individual in U.S. science policy with immediate access to the President and of the President's Science Advisory Committee (PSAC) and the OSTP should be included because it explains the relative absence of science policy at the higher levels of U.S. government. Until 1957, the President did not have an individual responsible for advising on issues of science. As a result of the Sputnik satellite surprise in 1957, President Eisenhower created the post of Special Assistant for Science and Technology and appointed James R. Killian, Jr., then president of the Massachusetts Institute of Technology, to fill it. At Killian's suggestion, Eisenhower moved the Science Advisory Committee that then existed under the Office of Defense Mobilization into the Executive Office. Together with the Committee, Killian developed a system for advising the President on science policy issues that grew and flourished until 1973, when it was abolished by President Nixon. The position was restored and established by law in 1979. During the 1957 to 1973 period, the role of the Science Advisor was well defined and very useful in formulating

basic science and technology policies for the U.S. After the reestablishment of the position of the Science Advisor and of the PSAC in 1979 their roles under Presidents Ford, Carter and Reagan declined.

A factor which contributed to this decline was the fact that the PSAC over time became what Lord Zuckerman (1988) calls "part of the political fabric of the White House," and began publicly to advocate "political actions" rather than "render judgments on science." Harvey Brooks, a distinguished U.S. physicist who served for many years on the PSAC, points out that over time the members of the PSAC failed to distinguish between the concepts of "policy for science" and "science for policy."

The root of these problems lies in the fact that the Office of Science Advisor and the membership of the PSAC were not civil servants but independent scientists appointed by the President and serving at the President's pleasure. As long as there was an agreement between the President and the members of the PSAC, the Office of Science Advisor functioned properly and effectively. When, however, disagreements arose, the proper functions of the PSAC were disrupted by issues such as political partisanship, scientific independence and objectivity. The membership of the PSAC and the Office of Science Adviser were always populated by very distinguished groups of scientists with national or world reputations who were capable and did from time to time disagree

with the President's views, and furthermore were willing and did make their disagreements public.

It is of some interest to compare the functions of the PSAC with its U.K. counterpart, the Central Advisory Council of Scientific Policy. Lord Zuckerman, for many years a Chief Scientific Advisor to Prime Ministers, states that when the PSAC operated in harmony with the political programme of the U.S. President, it ". . . was a far more effective advisory body ..." than the British counterpart.

However, in times of political crisis when political partisanship becomes a factor, the U.K. system is better.

The issue of political partisanship, independent and objectivity will always remain an open question. In dealing with it I would, however, commend the British system as a better model than the American. The post of chief scientific adviser to the British government follows civil service rules. Whatever party was in power, I served impartially, as all civil servants do. I was never expected to express -- and never did express -- a view about domestic issues that were the subject of party political debate. Nor was it ever expected that I would trim my own views about defence, or any other matters of policy with which I was concerned, to suit the views of the reigning party (Zuckerman, 1988).

The need for more visible science advice at the highest levels of U.S. government has been advocated by many over the last few decades. The most recent such recommendation was made to President Bush in the spring of 1988 by the Carnegie Commission of

New York chaired by Joshua Lederberg, president of Rockefeller University. It recommended that:

- a) "The president appoint a new Science adviser, and that the job be upgraded to Assistant to the President, a title that would bring with it direct access to the President.
- b) The Science Adviser head the Office of Science and Technology Policy (OSTP).
- c) The four Associate Directorships of OSTP, which have been vacant for many years, be filled by Presidential appointment. Two of those who fill the jobs should have dual appointments on the National Security Council staff and the Office of Management and Budget staff.
- d) The President appoints a panel of prestigious outside advisers, and the members should be willing to spend substantial time on the panel's work, unlike current White House Science Council members who meet for fewer than two days every few months." (Sanger, New York Times, December 18, 1988)

As of the summer of 1989, there has been no action taken on this by the White House.

Clearly the U.S. government is not ideally structured to design and implement science and technology policies. The sharp decline in U.S. advanced technology industries as clearly evidenced by international trade statistics and the alleged decline in the U.S. scientific and research performance, can be partly attributed to the U.S. government's science policymaking structure and institutions (Hatsopoulos, et al., 1988; Baumal, 1989; Cline, 1983).

Several other developments may have also contributed to the decline of U.S. advanced technology industries and scientific activities. One such development is the decline and redistribution of research and development funding by the federal government. The real growth rate of research and development spending, that is the percentage increase in research and development funds in the U.S., has significantly declined during the 1980's from about 7 percent in 1980 to about 2.8 percent in 1988. During President Reagan's administration, the federal government's support for research and development activities indeed increased by some \$29 billion, but almost 84 percent of the increase was for defence-related activities. Support for civilian research and development has actually fallen by 9 percent in real terms since 1980. The rise in the total U.S. federal government's research and development funding was driven by large increases in defence research (Tirman, 1984; Manufacturing Studies Board, 1988).

Another factor which may have contributed to this decline is the cumbersome process by which the U.S. Congress allocated research and development budgets. The allocation of public monies to the civilian research and development budget in the U.S. is indeed a complex and convoluted process (Bowen, 1980; CBO, 1985). A total of thirteen committees in the U.S. Senate and House of Representatives undertake the allocation process. There is very limited interaction between these; no unified review of

the research and development budget and no research priorities are established. This is in spite of the fact that some one hundred Senate and House Panels are engaged in the review of research and development funding requests prior to the time such funding requests reach the thirteen committees responsible for funding approval (Science, 28 August, 1988).

Furthermore, the members of the U.S. Congress are very susceptible to their own parochial interests and may allocate some research and development funds on a political rather than objective basis. Crawford (1988) states the following regarding the attempt by a U.S. Congressional Council to reform the funding process for some seven hundred federal government laboratories:

In conjunction with reorienting U.S. R&D policy, the council recommends that the role of the government's 700 laboratories in supporting the commercial application of technology needs to be examined. More resources should be directed toward R&D that is relevant to the needs of the private sector. To accomplish this, the activities of some federal labs will need to be redirected to support more applied research and in other cases laboratories should be closed where their work is of marginal utility.

The political obstacles posed by an effort to restructure and consolidate federal laboratories, the council concedes, will be large. Members of Congress usually regard these facilities as prized possessions and because the labs are often mission-oriented they also have industrial constituencies that will lobby on their behalf.

In conclusion, the science, technology and industry policies of the U.S. federal government, with few exceptions, consist of

U.S. government procurement and funding of science, technology and related activities from public monies. The U.S. government's structure, which supports in terms of administration and management these science policies, is divided among numerous U.S. federal government departments and agencies. Science policies are influenced by numerous interest groups. There have recently been a number of suggestions made to centralize this science policy-making apparatus in the U.S. (Golden, 1988).

It is not likely that any such attempts will succeed because of the long standing tradition in the U.S. of reducing and not increasing the power of the federal government. Raymond Vernon says the following regarding the attempts to undertake measures which will result in some type of unified science, technology or industry policies in the U.S.:

Americans should count themselves lucky that history seems to be moving in a direction that will limit the use of such measures. For if U.S. policymakers elected to develop a comprehensive national industrial policy, the odds are high that it would be applied in ways hurtful to U.S. national interest.

The basic difficulty is not venality or stupidity on the part of the U.S. government, as critics sometimes complain. Nor is it a lack of analytical capability on the part of U.S. bureaucrats; on the contrary, for probity and competence, our federal bureaucracy scores among the highest in the world. It lies rather in the deep-seated preference of the American electorate, affirmed again and again in the country's history, that the federal government deal with citizens with a very light hand, applying neither fear nor favor. That basic preference for limits on governmental power stretches back in history to the American colonists' fears of the Tudors and the Bourbons. And in the

centuries that followed, it was solidified by the country's almost unbroken history of economic growth and by the absence of any mortal threats from outside the country's borders (Vernon, 1988, 1989).

A similar observation on this issue is made by Jerome B. Wiesner, Science Adviser to Presidents John F. Kennedy and Lyndon B. Johnson and president emeritus of the Massachusetts Institute of Technology:

Some people proposed that what is needed is a new Department of Science, comparable in scale and complexity to the Defense Department. I agree that some kind of new agency should oversee civilian science, but it would be a serious mistake to sweep all government science projects into a single massive bureaucracy. Individual agencies should continue to manage their own scientific activities, and basic research should continue to be supported by the National Institute of Health, the National Science Foundation and other nationwide funding agencies (Wiesner, 1989).

11.4 U.S. GOVERNMENT SUPPORT FOR ADVANCED TECHNOLOGIES

11.4.1 U.S. Government Policies in the Microelectronics Industry

U.S. government policies to assist the microelectronics industry in the U.S. have varied in accordance with the three evolutionary phases of this industry in the U.S.: a) military gestation and incubation, from 1956 to 1962; b) commercialization, from 1963 to 1973; and c) large-scale integration and international competition, from 1973 to the present. The shift from one phase to another has been characterized by significant breakthroughs in microelectronics technology, diversification in end-product applications, as well as different kinds of U.S. government policies. Military-related demand, which accounted for

as much as 90 percent of total microelectronic products in the initial phase was replaced by commercial demand, during the 1963 to 1973 decade, required by U.S. computer and industrial equipment manufacturers with limited U.S. government involvement. This was followed by the last evolutionary phase of the microelectronics sector, beginning in 1973. During this phase, the U.S. federal government directed and funded large scale projects focused on defence-related uses of microelectronic products.

U.S. government policies related to research and development funding and procurement of microelectronic products were of the utmost importance at the inception of the microelectronics industry in the 1956 to 1962 period and to a lesser extent during the later development of integrated circuits in the early 1970's (Finan, 1981; Borrus, et al., 1982).

The two major U.S. government agencies which exercised these policies were the U.S. DoD and NASA. The DOD in particular virtually assured a market for all microelectronic products during the early phases of such products. Tilton (1971) for example estimates that in the case of one type of microelectronic device -- the monolithic integrated circuit, in the three initial production years (1962-1964) the DOD purchased 100 percent, 94 percent and 85 percent, respectively, of the total output. In

1968, six years after the introduction of the monolithic integrated circuit, the DOD purchased only 37 percent of the total output.

The enormous importance of these U.S. government policies should become even clearer when one considers the unit cost of these devices. The average unit value of monolithic circuits in the initial years of production was \$50.00; in the mid-1960's it had declined to \$31.60; and in the late-1960's, it had dropped to \$18.50. Thus, government procurement policies fostered the learning curve effect which in turn allowed for cost reductions and development of the industrial market. Asher and Strom (1977) concluded the following:

... the integrated circuit was dependent upon the technology of the semiconductor industry by both heavy R&D support and by providing a large market for high quality semiconductor products. Furthermore, following the invention of the integrated circuit, DOD again provided R&D support to its development and, probably more importantly, accelerated the use of integrated circuits by providing the early market which supported the development of production capability.

These conclusions are also supported by another study, prepared by Charles River Associates Incorporated (1981).

The combination of the rapid development of new devices and the assured demand provided by the government induced many firms to pursue innovative strategies and new market opportunities. As military production proceeded, learning economies were realized, costs fell, and firms were able to price products more cheaply, enabling them to penetrate consumer and industrial markets.

and

Many industry experts concur that military (and to a certain extent NASA) procurement of semiconductor devices had a strong, positive impact on the growth and development of the industry. Procurement contracts facilitated the speed of development of new devices and reduced the time needed for these devices to enter new markets.

Goldberg (1979) provides an excellent summary of U.S. government policies which assure markets for new technological products:

The Federal government effectively absorbs the risks inherent in the new technology by providing an assured outlet for an agreed quantity at predetermined prices and profit margins. Long-term contracts confer stability on the vendor. Production planning can proceed secure in the knowledge that it will not be subjected to disruptive variations in the volume and pace of manufacturing activity reflecting fluctuations in orders received. The stability of the long-term procurement contract accordingly provides an environment highly conducive to yield improvement and it is this which often lies at the root of the precipitate reduction in unit cost observable in the early production stage of a new device technology.

In addition to procurement policies, the U.S. government also contributed significantly to the development and growth of the domestic semiconductor industry by providing large research and development funds. As stated by Charles River Associates (1980):

Government funding of research and development for semiconductors originated in the Department of Defense and NASA as a means of developing new technology to meet the nation's military and space needs. These government agencies became convinced at an early stage of the

importance of semiconductor electronics to the military and space programs and therefore pushed for the development of more reliable, faster, and smaller circuits. The Air Force was an important source of R&D funds through its research programs for missiles and air defense. Between 1959 and 1964, Air Force integrated circuit R&D funding accounted for about 55 percent of total government R&D on integrated circuits in 1960. This "technology push" factor had an indirect impact on the industry by emphasizing the importance of research in this area and thus stimulated other firms to conduct extensive research activities.

R&D funding by the public sector proceeds in a manner similar to procurement. Basically, the government is "buying" a product as it does under procurement rules, but that product in this case is the research (and/or development) of a new product or process. R&D contracts can have either a relatively short term (one year) or a longer term (two to five years). During the 1950's the majority of R&D funds went to the "established" firms that had good reputations for research. However, by the early 1960's many of the newer, highly innovative companies were being given lucrative research contracts. RCA, Motorola, and TI were three of the major recipients of R&D funds in the early 1960's.

Two policy impacts may be immediately visualized. First is the effect on strategies. R&D funding by the government functioned to emphasize the urgency of the situation, thereby inducing greater R&D investments by private firms. Again, timing was all important. Government push in this direction of research compelled firms to follow, thereby increasing significantly the research effort toward developing new and better circuits. This government effort may not have been directly responsible for new innovations, but it certainly sped their realization.

Clearly, U.S. government policies provided major assistance in the initial phase of the U.S. microelectronic industry as well as in the development of integrated circuits by U.S. firms.

As the commercial markets for microelectronic products increased during the 1963 to 1973 period, the relative importance

of U.S. government procurement policies diminished, but continued to represent a stable market for U.S. firms. U.S. government support for research and development remained an important source of assistance to the industry; between 1970 and 1979, this funding averaged about \$40 million per annum, approximately one-half of the industry's research and development budget.

Defence consumption accounted for well over a third of total U.S. microelectronic product production from 1956 to 1962, reaching a high of 45 percent in 1958. Microelectronic products were used extensively for installation in Minuteman missiles and the Apollo spacecraft, which, by themselves, accounted for a large portion of defence consumption. Around 1963, with commercial opportunities rapidly expanding, the military proportion of total production began falling off. By 1977, defence-related consumption constituted only 12 percent of total production; but in absolute and constant dollars, the amount continued to rise steadily. Defence procurement rose to \$536 million in 1977, nearly ten times the figure twenty years before.

The data indicate that during the early years, the average price of microelectronic products sold to the DOD was several times higher than those sold on the open marketplace. This functioned, in effect, as a kind of hidden subsidy. Firms were able to set commercial prices lower than strict calculations of costs and profits would have allowed, because the comfortable margin of profits obtained from military sales could be used to

cover losses. Military procurements thus provided a solid foundation for the U.S. microelectronic companies seeking to establish a permanent basis for commercial operations (NAS, 1988; Moxon, 1983).

The combination of defence-related R&D and military procurements may have also enhanced the microelectronic industry's capacity to secure capital. By signalling the U.S. Government's confidence in, and commitment to, the industry's development, such tangible forms of support also helped to instill the kind of public confidence so necessary to secure financial backing: e.g., issuance of stocks and bonds, bank credit and loans, venture capital, etc. (Brinkman, 1988).

In the second phase of the microelectronic industry's evolution in the U.S., from 1963 to 1973, the principal government assistance to the industry consisted of providing a stable demand for a relatively small proportion of microelectronic products.

During the last phase of the microelectronic industry's development, starting in the year 1973, the government provided significant assistance to microelectronic firms by funding large scale research and development projects. The federal government has undertaken since 1972, and in particular during the late 1970's and 1980's, a number of programmes to support the native microelectronics sector. Some of these have been directed

explicitly at the research and development phase of the microelectronics sector, others have contributed to the design and production of advanced microelectronics devices.

11.4.1.1 Very High Speed Integrated Circuits (VHSIC) Programme

The U.S. VHSIC programme, initiated in the late 1970's, is funded and directed by the DOD and was the initial industrial cooperative research venture for the microelectronics industry in the U.S.

The VHSIC programme represents a \$900 million, fourteen-year effort (1976-1990) to meet military needs for highly specialized silicon-based digital integrated circuit technologies that will be used in various weapons systems, principally in ballistic missiles. The specific goal is the development of highly specialized semiconductor devices which perform according to rigid DOD specifications. The VHSIC programme has the overall objective of:

. . . the creation of chips with 'clock rates,' the speed at which they process data, of 25 million hertz, or cycles per second. The second is aimed at clock rates of 100 million hertz . . . Phase One of VHSIC achieved feature sizes of 1.25 microns, while Phase Two aims at half a micron . . . Some specific VHSIC projects include ones with application to 'smart' flying bombs, sonar buoys that detect enemy submarines, jamming pods for electronic warfare, radars, electronic packages for fighter aircraft, sonar-guided torpedoes, surface-to-air missiles, and tank weapon-control systems. (Gutmanis, 1983)

There are three main phases of the programme with the number of prime contractors decreasing in each phase. Phase Zero, launched in the late 1970's, involved programme definition by nine U.S. microelectronic product manufacturers:

- a. General Electric/Intersil
- b. Honeywell
- c. Hughes Aircraft/Signetix
- d. IBM
- e. Raytheon/Fairchild Semiconductor
- f. Rockwell
- g. Texas Instruments
- h. TRW/Motorola
- i. Westinghouse/National Semiconductor

Phase One involved the design and fabrication of 1.25 micron semiconductors. This included the design and fabrication of a viable prototype defence sub-system or brassboard, using Phase One chips. Six of the original nine contractors participated in this phase: Honeywell, Hughes Aircraft/Signetix, IBM, Texas Instruments, TRW/Motorola, and Westinghouse/National Semiconductor.

Phase Two, begun in late 1984, was devoted to half micron feature size semiconductors and was conducted by three of the Phase One contractors:

- a. IBM,
- b. TRW and Motorola, and
- c. Honeywell and Motorola.

Phase Three, instituted in 1986, has continued the research effort of the previous phase with the same participants.

A key aspect in the VHSIC programme is the potential commercial spillover. Transfer of VHSIC's accomplishments into commercial applications by U.S. microelectronic firms has occurred at a rapid pace. Of particular importance have been the benefits derived by U.S. microelectronic firms of advanced knowledge in the fabrication of microelectronics products, such as significantly improved lithographic processes used in the manufacture of microelectronic devices (SHC, 1988).

11.4.1.2 SEMATECH

In 1985, the U.S. microelectronic industry established the Semiconductor Manufacturing Technology Institute, or "Sematech," with the goal of undertaking research and development on production equipment used in the manufacture of microelectronic products (New York Times April 1, 1988).

Sematech is the first consortium of private firms to receive U.S. government funding. Formed by the Semiconductor Industry Association, Sematech received \$100 million in funding from its member companies and \$100 million from the DARPA.

"In overall dollar terms, the investment our government is making here is not large," said Robert Costello, Undersecretary of Defense for Acquisition. "Yet in terms of potential, the investment has enormous implications not only for a strong semiconductor

manufacturing base for America's defence, but also in providing a unique role model for other industries critical to the health and security of the nation." (NAS, 1988).

The idea for Sematech was derived from a Defense Science Board (DSB) task force report that found that shortcomings in the U.S. electronics industry's manufacturing base could undermine national security (Daniel, 1988).

Sematech's primary goal is to develop and integrate advanced materials, processes, and equipment into semiconductor manufacturing systems. To this end, Sematech has formed a subsidiary organization called Semi/Sematech, which consists of 150 U.S. materials and equipment manufacturers. Sematech is also funding research at 25 U.S. academic institutions and federal laboratories. As already noted, the DOD's strong support for Sematech has not been received with equal enthusiasm by all. The New York Times reported:

Another consequence is that the Defense Department is taking a more active role in planning, the industry sources said. Its role is controversial in any case. The consortium is not designed to develop computer chips directly for military use. Rather, the rationale for Pentagon involvement is that a healthy commercial semiconductor industry is vital for an overall healthy electronics industry in the United States, which in turn is vital for national defense. While the industry is grateful for the federal funds, some executives have hoped that the Defense Department would play only a small operational role in the consortium. They fear that too much Pentagon influence could poison the project because the department might insist on developing technology, such as the ability for chips to

resist nuclear radiation, that has military uses but is not applicable to commercial products (New York Times, April 1, 1988).

11.4.1.3 Microelectronics and Computer Technology Corporation

The Microelectronics and Computer Technology Corporation (MCC) was established in Austin, Texas in 1983, with partial government funding and leadership by the DOD, and has a decidedly national purpose: "to help maintain U.S. technological preeminence and international competitiveness in microelectronics and computers" (SHC, 1983). The MCC is owned by 21 American shareholder companies in both microelectronics and computers. The technical programme is focused on packaging, software technology, VLSI/CAD, and advanced computer architecture. The MCC had a budget of approximately \$62 million in 1987, \$87 million in 1988 and \$122 million in 1989 and a staff of scientists and engineers of over three hundred.

The MCC is unusual in that it found widespread bipartisan support in the U.S. Congress. Congress removed the major restraint to the founding of the MCC by passing the Cooperative Research Act of 1984, which allowed U.S. industrial firms to cooperate in certain kinds of long-range research and development projects without fear of antitrust regulations.

At present, the MCC is engaged in four research projects of importance to microelectronics product commercial applications (Spring, 1989): "packaging" (development of architecture of microelectronic components); "software technology" (producing procedures and computerized tools that simplify the task of writing complex programmes for specialized applications); "very large scale integration/computer-aided design" (developing a set of tools that can be applied to the design of complex integrated circuits), and "advanced computer architectures." The last programme is itself split into four separate research programmes: "parallel processing" (hardware and software that enable computers to operate at high speed and to solve certain kinds of complex problems by performing many parts of a task simultaneously); "data-base-system management" (methods of storing and retrieving complex information); "human-factors technology" (flexible means of communication between human beings and computers, perhaps including speech or handwriting); and "artificial intelligence [AI]/knowledge-based systems" (computer systems that make decisions by applying new ways of storing knowledge).

11.4.2 The Machine Tool Industry in the United States

The U.S. machine tool industry experienced a rapid growth in the second half of the 19th Century, but has experienced a decline in the recent past. According to Daly and Jones (1987):

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).

In the 1960's, when advanced machine tools and robotics were introduced in the U.S., the growth pattern of this industry was dampened by two major factors: first, the hourly cost of direct labour was lower than the hourly cost of operating an advanced machine tool or industrial robot; and second, the benefits expected from the new, unproven technology were still uncertain. As a result, by 1970, ten years after their introduction, only about 200 industrial robots were in use throughout the U.S. (Fawcett, 1976).

During the 1970's and 1980's, however, the U.S. economic environment changed significantly. Manufacturing productivity declined steadily and labour costs increased, while machine tool and robot costs did not rise excessively. These trends were taking place at the time when machine tools and robots were becoming more sophisticated in both manipulative and control/sensing capabilities. Usage of robots in U.S. manufacturing began to increase significantly in the late 1970's. The robot popula-

tion in the U.S. increased from about 200 in 1970 to about 1700 in 1978 and facilities increased to about 6000 in 1988 (Feeder, 1988).

The U.S. government's role in assisting U.S. machine tool makers is primarily centred on research and development funding through the DOD, NASA, the NSF, and the National Bureau of Standards (NBS). The objective of DOD funding was to develop manufacturing technologies with specific military applications. NASA's funding was focused on space-related automation technologies. The objective of NSF funding was to assist applied research projects undertaken by U.S. universities. The objective of NBS funding was to provide support for automation research.

11.4.2.1 Department of Defense

Most of the DOD sponsored research in machine tools and manufacturing automation technology is conducted under its Manufacturing Technology Program (ManTech), with funding of \$200 million per annum. ManTech essentially began in 1960 with the aims of developing and applying productivity-enhancing manufacturing technologies (DOD, 1986).

There were about 400 to 500 ManTech projects active in the U.S. machine tool industry in 1989. In addition to the ManTech programmes, two other DOD agencies fund longer term, more basic

research in the machine tool sector. The DARPA funds research in robotics, sensory control, and artificial intelligence, while the Office of Naval Research (ONR) supports university-based research in precision machine tools.

11.4.2.2 National Aeronautics and Space Administration

NASA's funding of the machine tool sector has averaged about \$7 million per annum during the last decade. Three specific areas are the focus of NASA's funding: 1) robotics and teleoperator research to develop manipulators for applications on space missions; 2) development of an advanced computer-aided planning systems, and 3) integrating and computer-aided engineering systems and linking them with data management software packages.

11.4.2.3 National Science Foundation

The NSF, with an annual budget of about \$10 million for machine tool research and development, provides support for programmes with application to manufacturing automation. The various areas of research include discrete manufacturing, CAD, CAM, computer-aided testing, robotics use in materials handling, touch and vision sensors, robot programming languages, computer architectures, and control systems (NSF, 1986).

11.4.3 U.S. Government Policies in Advanced Materials Sectors

The advanced ceramics sector has been the focus of U.S. government support among advanced materials industries (Beinent, 1986). The government has sponsored R&D in advanced ceramic engineering products since the early 1970s. Much of this support (around \$350 million from 1971 to 1988) has been aimed at vehicular engines, reflecting the potential impacts of advanced ceramics on fuel efficiency. In 1987, the U.S. federal government spent almost \$23 million for R&D in engineering ceramics (Table 11.3). Many of these programmes in the early 1970s were first funded by the DARPA, and later picked up by the DOE.

Within the federal government, DOD (DARPA) research and development has been focused on adiabatic diesel engines, particularly for tanks, on automotive engine propulsion, and on aerospace engines. In addition, several U.S. National Laboratories are engaged in basic research on advanced ceramics, including the Argonne National Laboratory, the NBS, the Naval Research Laboratory, the Army Materials and Mechanics Research Center, and the Oak Ridge National Laboratory (Johnson, et al., 1983).

A large portion of U.S. federal government monies is actually provided to private industry, especially for product design and testing (U.S. DOC, 1984). A list of U.S. private

sector contractors, subcontractors, and suppliers to the DOE advanced engineering ceramics effort is shown in Table 11.4. Funding is also provided to 24 U.S. universities which have substantial advanced engineering ceramics programmes such as MIT, Rutgers, and Pennsylvania State University.

U.S. government policies, research and development funding and other assistance to the advanced polymer and composite manufacturers cannot be discussed because most of the advanced polymers and composites are produced for defence-related application. The very limited information available suggests that the U.S. government provides funding for some sixty research and development projects undertaken by U.S. universities and private sector firms. At least seventy-seven U.S. federal government laboratories are engaged in activities related to advanced polymer and composite research.

6.5 CONCLUSIONS

The science, industry and technology policies of the U.S. federal government are limited to government procurement and funding of research and development activities. The U.S. government funds research and development either directly by allocating public monies to U.S. government laboratories and private sector research entities, or undertakes funding of large scale research and development projects. There is no central science,

TABLE 11.3

Engineering Ceramic Technology
Federal Government Funded, R&D 1987

<u>Agency</u>	<u>Amount</u> <u>(\$ Million)</u>
Department of Energy	
Vehicle and Engine Research and Development	\$ 9.28
Industrial Program	0.32
Energy Systems Research	0.20
Advanced Research and Technology Development	1.23
Advanced Energy Conversion Systems	1.93
Surface Coal Gasification	0.30
Basic Energy Science	1.00
NASA	
Lewis Research Center	1.50
NSF	1.00
Department of Defense	
Defense ARPA	2.00
U.S. Air Force	1.70
U.S. Army	1.27
U.S. Navy	<u>1.00</u>
Total	\$22.83

Source: U.S. Dept. of Energy, Office of Vehicle and Engine R&D,
1989.

TABLE 11.4

Private Sector Contractor, Subcontractors, and
Suppliers to DOE Advanced Engineering Ceramics R&D

Garrett Turbine Engine	SKF Industries
G.M. Allison Gas Turbine	GTE Labs
Ford Motor Company	IIRT
Cummins Engine Company	Norton Company
Airearch Casting Company	Pure Carbon Company
Carborundum Company	COORS Porcelain Company
Dow Corning Company	AC Spark Plug
General Electric Company	ERG
TRW Corporation	Kyocera International
	NGK Insulators

Source: U.S. Department of Energy, 1989.

technology or industry policy making apparatus in the U.S., rather the policymaking structure is one of dispersed interest groups with both competing and complimenting interests.

The absence of a central science, technology or industry authority in the U.S. may be partly explained as the result of society's innate suspicion of government intervention. The fact, however, that science and technology activities in the U.S. take place in a very large number of enterprises (there are over 700 research and development entities alone), makes it very difficult to establish a central government authority over these entities.

In the light of the decline in the performance of some advanced technology sectors (especially when this performance is measured in terms of trade), it is likely that some additional control over science and technology policy by the U.S. federal government will be attempted (U.S. ITC, 1984; Hiets, 1988). The obvious location of such additional control would be in the Executive Office of the President. The present Office of Science and Technolody Policy located in the White House has not been allowed to perform with either legal or political authority during the last several decades, although this office performed well in the 1960's.

In addition to the poor performance by advanced technology industries in terms of declining exports and sharply increasing imports, there are two other major deficiencies in U.S. science

and technology activities which may require policy guidance by the U.S. federal government. The first of these is the unwillingness or inability of private sector firms to allocate funding for research and development for sufficiently long-term periods in order to obtain the benefits from these activities. The current corporate culture of the U.S. requires that benefits from any corporate expenditures are shown four times during a year in quarterly financial reports. Funding of research and development activities which would reap results at some time in the future are discouraged. As the distinguished U.S. economist and member of the prestigious National Academy of Engineering, Professor Rosenberg states:

The resulting preoccupation with short-term problems has contributed to an economic environment inhospitable to the stability required for carrying out long-term R&D strategies. (Rosenberg, 1988)

The unwillingness or inability by private sector corporations to allow sufficient elapsed time for their research and development projects to become profitable have resulted in the loss of very large potential future revenue sources (Bowen, 1980). For example, the present sales volume of VCRs in the U.S. alone is estimated at \$5 billion. The U.S. does not have a single manufacturer of VCRs. Rather, almost all of the VCR units sold in the U.S. have been produced by Japanese firms. The research, development, design and engineering work for the VCR was, however, conducted by a relatively small U.S. firm, Ampex Corporation,

which sold its completed VCR technology to Japanese firms in order to generate immediate cash flow into the corporation. Likewise the principal microelectronic components on the world markets--the various "memory" devices, were developed by U.S. firms and sold for immediate cash to the Japanese. The total world-wide annual market value of the "memory" device is approximately \$12 billion. The Japanese manufacturers produced over 80 percent of these devices in 1988.

The other principal area where the U.S. government may need to enact appropriate policies in order to improve the competitive position of the U.S. is in manufacturing technologies. The technological advances in the United States' manufacturing processes for many industry sectors (including advanced technology sectors) have not kept pace with those of international competitors such as the Japanese.

In a recent study, the Manufacturing Studies Board, National Academy of Sciences, states the following:

Japanese companies have concentrated on manufacturing as their core competence. In contrast, manufacturing processes in the United States have been a secondary consideration. United States managers do not emphasize manufacturing as a means of achieving world leadership in electronics. The manufacturing function and managers in charge of manufacturing activities have tended to be less influential than their research-and-development and marketing counterparts. As a result, the Japanese have captured the bulk of the world's consumer electronics business by emphasizing careful attention to the details of electronics hardware manufacturing (NAS, 1988).

The U.S. federal government has undertaken only marginal or limited intervention in advanced technology sectors. In the case of microelectronics, this industry sector has declined in the U.S. from a premier position in the world to one in which the U.S. must share the world markets with the Japanese.

Analyses of the U.S. microelectronic sectors, science, research and development activities and technology advancement clearly establish the fact that the performance of the U.S. in these areas up to the late 1970's was equal or superior to its chief competitor -- the Japanese. Yet, the U.S. microelectronic industry has lost ground steadily to its Japanese competitors from the late 1970's to the present time. The principal, most likely reason for this decline was the inability of U.S. microelectronic product manufacturers to expend the very large funds required to design, engineer and construct microelectronic product manufacturing facilities.

As presented elsewhere in this volume the capital cost requirements for microelectronic product manufacture, driven by very rapidly advancing technologies were increasing at a phenomenal rate (U.S. DOC, 1985). U.S. microelectronics enterprises could not obtain the required monies from either internally generated funds or from public offerings. Funding assistance from the federal government represented the only remaining possibility for obtaining the required capital funds.

The required action by the U.S. federal government, in the light of the general reluctance by the U.S. to disrupt free market functions, was not offered and perhaps was not politically feasible. Conversely, Japanese firms, partly because of Japan's unique banking system and financial markets, were able to obtain the required funds for capital expenditures (SHC, 1988; Steel, et al., 1985).

Japanese microelectronic product facilities constructed in the late 1970's and early 1980's employed the most advanced production equipment and were very large and therefore able to take advantage of economies of scale and reduce unit production costs. As of the mid-1980's, the Japanese enjoyed absolute cost advantage over U.S. microelectronic firms. World-wide microelectronic product market penetration by the Japanese was the obvious outcome. The above chain of events, as noted, took place in the late 1970's and early 1980's. These events may be repeated again in the near future as described by Hector:

Demand for capital is already vast -- and growing. A first-rate fabrication facility for mass-produced memory chips now runs about \$200 million. By the early 1990s the cost will easily top \$300 million, as each new generation of products requires larger and more expensive equipment. G. Dan Hutcheson, an analyst at VLSI Research, a market research firm in San Jose, California, suggests that if current advances in technology continue, sometime in the 1990s the cost of such a facility could hit \$1 billion -- a sum beyond the reach of almost any U.S. chipmaker except IBM or AT&T. Yet Japanese semiconductor companies, which are part of larger corporate groups like NEC and Toshiba, are big enough to handle that kind of investment." Japan's

large, vertically integrated companies can invest heavily and accept low rates of return for long periods in order to gain market share. IBM and AT&T can match the investment if necessary, and niche chipmakers can simply avoid competing with the Japanese, but other large U.S. merchant manufacturers, particularly Intel, AMD, and National, cannot avoid some direct Japanese competition and probably don't have the stamina to withstand it (Hector, 1988).

Clearly, some appropriate policy by the U.S. federal government may be desirable to forestall the further decline of U.S. micro-electronic firms.

The U.S. government's willingness to undertake appropriate policies may not, however, suffice to save the U.S. microelectronic industry. Equally important is the cooperation of the U.S. microelectronic firms themselves. However, a significant number of the microelectronic product manufacturers in the U.S. are smaller, "niche" firms with a strong bias against U.S. government involvement of any kind in their enterprises.

As reported by Richards (1989), regarding the microelectronic industries response to the U.S. government's assistance in the SEMATECH project:

Most of the large chipmakers -- the top five control half of the market -- for example, favor at least a limited partnership with government. But the industry's smaller, more entrepreneurial companies are determined to go it alone. Among the most outspoken is T.J. Rodgers, founder and president of Cypress Semiconductor Corp. of San Jose. Rodgers considers Sematech a flawed concept nourished by a \$100 million "bagful of candy" from government.

In Japan, of course, government policies can be more or less successfully "forced" on the private industry sectors. In the U.S. this may not be feasible.

The U.S. machine tool sector has declined substantially during the last several decades. U.S. government policies to arrest this decline have been very modest (Stanley, et al., 1982). The principal reason for the reduction in U.S. machine tool makers production, sales, exports and profits was their inability to absorb the advanced technology used in machine tools, that of microprocessors and related devices.

Machine tool makers in the U.S. (as well as in France and the U.K.) were principally "steel men," machine shops which engineered various metal cutting devices with mechanical power sources. Many of these shops were small, owned and operated by experienced master metal workers, machinists, even mechanical engineers. These enterprises were not technically able to understand, absorb and put to use in their shops the micro-electronics technology with which they had had essentially no previous contact.

In the light of the above, it is doubtful if any U.S. government policy would have been able to arrest the decline of the U.S. machine tool sector.

Advanced materials sectors represented the cutting edge of several technology areas. Information on U.S. government policies in these sectors is scarce due to the defence-related uses of these advanced materials. Fragmentary evidence suggests, however, that the U.S. government policies essentially dominate this industry sector by virtue of its almost total dependence on military products.

FOOTNOTES TO CHAPTER 11

- (1) There exists another relatively widely accepted categorization of industrial nations with regard to technology policies. A well prepared statement of this can be found in the chapter prepared by Henry Ergas, a trade councillor at the OECD, in a Guile and Brooks (1987) report on a recent symposium on technology and social priorities organized by the U.S. National Academy of Engineering. Ergas, in his chapter "Does technology policy matter?", compares technology policies in different countries and finds that they basically fall into three groups.

In "mission-oriented" countries (such as the U.S., the U.K., and France), governments generally try to boost the emergence of a specific emerging technology -- the breeder reactor, the space programme, or the supersonic airplane. In contrast, countries pursuing "diffusion-oriented" policies (Switzerland, Germany, and Sweden) do not target specific technologies, but rather construct environments -- through strong support of education, cooperative research efforts by universities and industry, and industry standard-setting-- that are designed to promote the development of mature products and processes. Only Japan has taken a third course, mixing elements of each of the first two strategies but focusing its greatest effort on assisting industries in their

"consolidation phase" -- well after new technologies have emerged but before final product designs have been established.

- (2) These attempts originate for the most part from elected representatives in the U.S. Congress, particularly those which represent geographic areas with declining industrial employment. It should be noted that, for the most part, the declining employment takes place in the so-called "rust belt", located in the midwest region of the U.S, with a significant concentration of iron and steel processing firms.

CHAPTER 12:

JAPANESE GOVERNMENT POLICIES

12.1 INTRODUCTION

Japan's economic growth during the last three decades has been pronounced and accelerating, especially since the early 1980's. The increase in the GNP of Japan, which in 1987 was valued at \$1231.1 billion (in constant 1982 dollars) was matched by a large increase in its current account balance, which has shown an exceptional growth since 1981.

Japanese exports, a very large portion of which are exports of advanced technology products, as a percentage of the Japanese GNP have shown significant annual fluctuations, but a secular growth trend since 1967. This growth and development of the Japanese economy is surprising in the light of the fact that the advanced technology sectors in Japan are responsible for much of this outstanding economic performance at home and in export markets.

It is surprising because Japanese achievements in science and technology have been modest in the past. For example, only 5 Nobel Prizes have been awarded to scientists born in Japan to the U.S.'s 188; France's 87; the U.K.'s 101; and Germany's 62. Japanese scientists have been responsible for very few tech-

nological innovations in the post-World War II period. A review of the world's scientific literature in physics, chemistry, biology, mathematics, etc. authored by Japanese scientists is modest as compared to scientists from the U.S., the U.K., the Soviet Union or Germany. There exists, however, almost unanimous agreement that in the application of innovations and advanced technologies, developed elsewhere, the Japanese have performed extremely well (Johnson, 1982).

Much of the credit for this must be awarded to the Japanese government's science and technology policies. The Japanese government has exercised a direct influence on the nation's science and technology activities, with numerous notable successes in most advanced technology industries (Gerstenfeld, 1982).

The Japanese government's role in directing the nation's economy, science, and technology activities has a long history.⁽¹⁾ Since the beginning of the Meiji era (in 1868), Japan has used various industrial policy measures to shape the structure of its economy and to direct productive resources toward certain technological, industrial, and social goals (Johnson, 1982). In the initial decades of the Meiji period, the Japanese government directed the transformation of the Japanese economy from a technologically primitive, essentially rural society to an industrialized nation, surpassing all other countries on the Asian continent. In the 1920's and 1930's, Japanese governments directed

industrial development with a heavy hand to prepare Japan for its conquest of Southeast Asia and ultimately to confront the Allies. In the immediate post-World War II period, Japan's economic and industrial policies were directed towards recovering its economy from the destruction of WWII. Yamamura (1986) summarizes this period in Japanese economic history as follows:

First the Japanese had a strong, shared motivation -- a national consensus -- to recover as quickly as possible from the humiliation of defeat in World War II and to achieve rapid economic growth, which was regarded as the only means to regain national pride. This consensus made a progrowth policy (explicitly favoring growth over equity) politically possible and ensured the uninterrupted dominance of the conservative Liberal Democratic Party (LDP) over the next thirty years. Unlike in England (and elsewhere to a varying degree), there was little danger of debates on progrowth policies becoming ideological debates over distribution, which would have rendered the policies finally adopted totally ineffective, if not perverse; and

. . . Japan's institutions have been crucial in determining the type of policy adopted. . . . few can quarrel with the observation that Japan's resilient LDP government, supported by rigorously selected elite bureaucrats in the ministries in Tokyo, commanded more power and a wider range of policy tools at its disposal than did, for example, the American or British counterparts. France comes closest to having an equally "strong" bureaucracy, but its political stability cannot be compared to that enjoyed by Japan.

The Liberal Democratic Party in Japan created an economic consensus in Japan, referred to as the "grand coalition." This consisted of: the "labour intensive" sectors of society and big businesses -- the large corporations which were then and are now at the heart of Japan's industrial development.

Japanese science and industrial policy for the last hundred or so years has been primarily planned, designed and executed by Japan's central bureaucracy which occupies a much more important place in the national government than do its counterparts in the U.K., the U.S., France or Germany (Sakikabara, 1982). The ministries in Tokyo, led by career bureaucrats recruited from elite universities, draft most of the legislation that comes before the Diet, exert extensive control over the financial system, prepare the national budget, and use their substantial discretionary power to influence scientific, technological, and economic activities through what the Japanese call "administrative guidance." This flexible, quasi-legal "guidance," backed by implicit threats and rewards, not explicit legal authorization, is the backbone of Japanese science, technology, and industrial policy. To a considerable extent this type of government intervention in Japan continues to the present time (Fuji, 1983). The Japanese government "guidance" in matters concerning science and technology is one of the instruments which accounts for the present growth of Japanese advanced technology industries. Government policies in the immediate post-World War II period were much more autocratic compared to current Japanese policies, although these policies created an economic environment conducive to technological advancement and economic growth. Specifically, these policies in the late 1940's and 1950's directed and restricted investment, controlled technology imports, and

implemented a tax system which encouraged significant investments in the Japanese economy (ITC, 1986).

The success of these policies in terms of economic redevelopment and growth in Japan cannot be denied. However, these policies represent the most direct government involvement in a nation's economy, short of complete governmental control. A summary description of these policies serves as background information for current Japanese policies (ITC, 1986).

Directed Investment in Japan was accomplished by the application of two "temporary" laws enacted in 1949 and 1950 and remaining in effect throughout the 1950's. The Japanese Ministry of Finance (MOF) made loan capital available to the largest banks in Japan (the thirteen "city" banks), which in turn were "guided" to make loans available to specific industry sectors and even specific firms. The MOF and MITI maintained a standing committee to identify the industries and the firms to benefit from the former's "guidance."

Control of Technology Imports was an important source of MITI's power in the 1950's, 1960's and 1970's. MITI acted as a "doorman" to all vital imports of Western technology which Japanese firms sought out and purchased. Because prior approval by MITI for the purchase of foreign technology was required, MITI was able to dictate the timing, composition, and allocation of a

flow of technical knowledge that was essential to the competitive success of innovating Japanese firms.

The Japanese tax system was designed to favour savings and investment. Japanese fiscal authorities accomplished this by:

- a) reducing double taxation of corporate income through preferential treatment of dividends;
- b) excluding from taxable income the interest income of small savers;
- c) favouring capital gains over dividend income; and
- d) keeping the average tax burden (combined with a high savings rate) low as compared with other industrialized countries.

During the period beginning in 1951, i.e., at the end of occupation and lasting until about 1954, Japan's policies were autocratic and singularly focused on the economic reconstruction of the Japanese economic base.

During the 1955-64 period, the Japanese government focused on "catching up" with the U.S. and European nations.

From the year 1964 to the present, Japanese science, technology and industry policies have been designed and implemented to achieve a pre-eminent status in the world's market for advanced technology products as well as for such commodities as steel, automobiles, consumer electronics, and others (SHC, 1988).

The essentials of Japanese industrial policy since 1964 have been the deliberate protection of domestic markets from foreign sources and the oligopolization of major domestic industries. This has allowed Japanese firms to set high domestic prices for products in the domestic market. Japanese firms in selected or "targeted" sectors are guided initially to expand their production and sales in the domestic market. The expansion of production results in a large volume of production and relatively low production costs which in turn allows these firms to compete in the world markets. One of the principal policy tools the Japanese government in general, and MITI in particular, have used to assist specific industry sectors in Japan were so-called "temporary measure laws" enacted for limited time periods with the specific objective of assisting a targeted industry (Inose, 1979; Japan Society for Promotion of Science, 1987).

The two principal temporary measure laws were the Law on Extraordinary Measures for the Promotion of Specific Electronic and Machinery Industries, or "Kidenho", and the Law on Extraordinary Measures for the Promotion of Specific Machinery and Information Industries, or "Kijoho." The Kidenho, which was in effect from 1971 to 1978, combined a series of promotional measures for the Japanese machinery and electronics industries. In 1978, the Kijoho was enacted, and lasted until 1985, with the objective of promoting Japanese software development.

The Kidenho provided government support for research and development, commercial production, and manufacturing improvement in the Japanese microelectronics industry. With this support Japanese microelectronic product firms developed advanced technologies in integrated circuits and eventually produced third generation computers. The Kidenho empowered MITI to provide government assistance through "enhancement programmes" to the Japanese electronics firms in close cooperation with the Electronic and Machinery Industry Council. It also allowed MITI to direct certain joint activities which were exempted from the Antimonopoly Law (ITC, 1986; SHC, 1988).

12.2 SCIENCE, RESEARCH & DEVELOPMENT, AND INDUSTRY POOL IN JAPAN

There are three principal institutions in Japan engaged in science and technology activities: higher educational establishments; private industry sectors; and non-profit research institutions and Japanese government agencies.

12.2.1 Higher Educational Establishments

There are three categories of higher educational establishments in Japan: national universities, administered by the Japanese central government; public universities, operated by prefectural (i.e., local) governments; and private universities.

National universities are responsible for over one-half of the scientific research and development and related activities, while private universities expend some 38 percent of research funds allocated to higher education institutions in Japan. Public universities operated by prefectural authorities undertake limited scientific and research activities (Table 12.1).

In 1971, the so-called "national inter-university research institutes" were established at several of Japan's universities. The number of these institutes has increased and now represents an important resource for scientific, research, development and technology activities in Japan (Table 12.2).

12.2.2 Industry

Japanese private sector firms represent an important component of establishments which perform science and technology related activities in Japan.

Most of the science, technology, research and development effort undertaken by Japanese industry sectors is concentrated in large industrial enterprises. Most of the funding for these activities is obtained internally (ITC, 1983).

Japanese private sector firms receive very limited funding from the Japanese central government, averaging at less than 2

TABLE 12.1

Expenditures for Science and Technology
Activities by University Type, Japan, 1981

University Type	Science and Technology Expenditures
National	57.1%
Public	5.4
Private	<u>37.5</u>
	100.0

Source: Indicators of Science and Technology (1987), Science
and Technology Agency, 1987, Japan

TABLE 12.2

Joint and National Inter-University
Research Institutes, Japan

University of Tokyo

Institute for Cosmic Ray Research
Institute for Nuclear Study
Institute for Solid State Physics
Ocean Research Institute

Nagoya University

Institute of Plasma Physics

Kyoto University

Research Institute for Fundamental Physics
Research Institute for Mathematical Sciences
Research Reactor Institute
Primate Research Institute

Osaka University

Institute for Protein Research
Welding Research Institute

National Laboratory for High Energy Physics

National Institute of Polar Research

Institute of Space and Astronautical Sciences

Okazaki National Research Institutes

Institute for Molecular Biology
Institute for Basic Biology
Institute for Physiological Sciences

Source: An Outline of the University-based Research System in Japan. Monbusho, Japan 1987

percent per annum of the total industry expenditures for science and technology during the last several decades (SHC, 1988).

12.2.3 Nonprofit Research Institutes in Japan

Four types of non-profit research institutes undertake science and technology related activities in Japan: national government-owned, local government-owned, private, and public corporations. The U.S. National Science Foundation reports that the distribution of activities are as follows: 13.1 percent for basic research, 33.4 percent for applied research and 43.5 percent for development activities.

Japanese central government operated research institutes are established by many Japanese government ministries. MITI and its Agency of Industrial Science and Technology operates 16 such institutes. The Science and Technology Agency of the Japanese Prime Minister's Office operates a total of seven research institutes in Japan. Personnel in all of these institutes are Japanese civil servants (Johnson, 1982).

Essentially all large Japanese corporations have established separate non-profit research entities to perform science, technology research and development activities. The three principal institutes are the Mitsubishi-Kasei Institute of Life Sciences,

Matsushita Tokyo Research Institute, and Japan Light Metals Research Institute.

Close cooperation exists between these institutes and the Japanese private sector. Furthermore all Japanese central government departments and agencies utilize a large number of advisory councils from industry executives to guide Japanese government-conducted academics in science and technologies activities. A listing of research institutes operated by the Japanese government is presented in Table 12.3.

12.3 JAPANESE GOVERNMENT AGENCIES RESPONSIBLE FOR SCIENCE, TECHNOLOGY, RESEARCH AND DEVELOPMENT POLICY FORMULATION

Four principal Japanese central government agencies formulate and execute Japanese government plans and policies for economic, science, technology and industry activities.

Overall economic policy in Japan is formulated by the Economic Planning Agency (EPA); science, technology and industrial policy by MITI; and monetary and fiscal policy, by the MOF and the Bank of Japan (BOJ).

TABLE 12.3

**Principal Government Research Organization
and Institutes, Japan**

SCIENCE AND TECHNOLOGY AGENCY

National Aerospace Laboratory
 National Research Institute for Metals
 National Institute of Radiological Sciences
 National Research Centre for Disaster Prevention
 National Institute for Research in Inorganic Materials
 National Institutes of Resources
 Japan Atomic Energy Research Institute
 Power Reactor and Nuclear Fuel Development Corporation
 Japan Information Centre for Science and Technology
 Institute of Physical and Chemical Research
 Research Development Corporation of Japan
 Japan Nuclear Ship Research and Development Agency
 National Space Development Agency of Japan
 Japan Marine Science and Technology Centre

DEFENCE AGENCY

Technical Research and Development Institute

HOKKAIDO DEVELOPMENT AGENCY

Civil Engineering Research Institute

ENVIRONMENT AGENCY

National Institute for Environmental Studies
 National Institute for Minamata Diseases

MINISTRY OF FINANCE

Research Institute of the Government Printing Bureau
 National Research Institute of Brewing

MINISTRY OF EDUCATION, SCIENCE AND CULTURE

National Science Museum
 National Institute of Genetics
 Institute of Statistical Mathematics
 International Latitude Observatory

MINISTRY OF HEALTH AND WELFARE

Institute of Public Health
 National Institute of Mental Health
 National Institute of Nutrition
 National Institute of Health
 National Institute for Leprosy Research
 National Institute of Hygienics Sciences
 National Institute of Hospital Administration
 Institute of Population Problems

TABLE 12.3 (Continued)

National Cardiovascular Disease Centre
National Cancer Centre

MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES

National Institute of Agriculture Science
Agricultural Research Centre
National Institute of Animal Industry
National Grassland Research Institute
Fruit Tree Research Station
Vegetable and Ornamental Crops Research Station
National Research Institute of Tea
Agriculture Experiment Station
National Research Institute of Agricultural Engineering
National Research Institute of Agricultural Economics
Sericultural Experiment Station
National Institute of Animal Health
National Food Research Institute
National Institute for Plant Virus Research
Tropical Agriculture Research Centre
Forestry and Forest Products Research Centre
Regional Fisheries Research Laboratory
National Research Institute of Aquaculture
National Research Institute of Fisheries Engineering

MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY

National Research Laboratory of Metrology
Mechanical Engineering Laboratory
National Chemical Laboratory for Industry
Electrotechnical Laboratory
Industrial Products Research Institute
National Research Institute for Pollution and Resources
Fermentation Research Institute
Research Institute for Polymers and Textiles
Geological Survey of Japan
Government Industrial Development Laboratory -- Hokkaido
Government Industrial Research Institute -- Osaka; Nagoya;
Kyushu; Tohoku; Shikoku; Chugoku

MINISTRY OF TRANSPORT

Ship Research Institute
Port and Harbour Research Institute
Electronic Navigation Research Institute
Traffic Safety and Nuisance Research Institute
Meteorological Research Institute

MINISTRY OF POSTS AND TELECOMMUNICATIONS

Radio Research Laboratory

TABLE 12.3 (Continued)

MINISTRY OF LABOUR

Research Institute Laboratory
National Institute of Industrial Health

MINISTRY OF CONSTRUCTION

Geographical Survey Institute
Public Works Research Institute
Building Research Institute

MINISTRY OF HOME AFFAIRS

Fire Research Institute

Source: Japan, Science and Technology Agency, 1987.

12.3.1 The Economic Planning Agency (EPA)

The EPA is located within the Japanese Prime Minister's office. The EPA formulates general plans for Japan's economy including trade, production, prices, consumption, and government income and expenditure policies. The EPA essentially provides a policy framework for the entire set of Japanese macroeconomic activities. The economic framework established by the EPA is general, but is considered of singular importance by private sector firms in Japan.

12.3.2 The Ministry of International Trade and Industry (MITI)

MITI plans and enacts all of the specific science, technology and industrial policies in Japan. MITI also enacts and supervises specific Japanese trade policies, environmental laws, energy and natural resource policies, small business, and regional development policies. From the mid-1950's to the early 1980's, MITI officials had effectively "regenerated" private sector research and development activities, managed innovations in industrial sectors and supervised the introduction of advanced technologies. MITI's "regulation" of these critical trends was accomplished through the unique Japanese approach to industry policies, best described as "administrative guidance" (ITC, 1983).

The Industrial Structure Division of MITI's Industrial Policy Bureau is the principal agency within MITI which provides administrative guidance and in effect plans, formulates and executes science, technology and industrial policies in Japan. This process is closely coordinated with the Japanese private sector represented by the Industrial Structure Council, an advisory body comprised of industry executives and academics to the Industrial Structure Division.⁽²⁾

Periodic publication of general plans for future development of specific economic sectors in Japan by MITI, the so-called "visions," provide overall guidance and inform the Japanese public of the government's economic, industrial and social policies.

Since the end of World War II, the Japanese government has issued three such visions, all formulated by MITI. As noted, Japanese visions, or Bijou, are coherent but unspecific programmes for future trends they will attempt to accomplish by other, more specific policies. MITI's visions may differ markedly from the EPA's economic plans, in that visions are not specific with regard to production goals of targeted industries, availability of advanced technologies, investment recommendations and other related instructions. The visions provide, however, a common development plan for all sectors of the Japanese economy and all participants in economic activities (Anderson, 1984).

The Industrial Structure Council also issues very specific reports and recommendations for industry sectors in Japan. These reports contain detailed analyses of prospects and problems for growth in special industries including recommendations for scientific activities and the adaptation of advanced technologies for specific industries. These reports also include information on cost structures of important industries in Japan, and different technologies and scales of production, with similar information for foreign countries and foreign firms which may be competitors for Japanese firms. These reports represent the cardinal document, issued on a periodic basis for industrial policy in Japan (SHC, 1988).

MITI's principal activity, with regard to science and technology policies, prior to the mid-1980's was to select so-called "target industries" in Japan, i.e., destined for favourable treatment by the Japanese government. The following were the criteria used by MITI to select the "target industries":

- a) Value added -- MITI's policy favoured industries that produced a high percentage of the final value of output such as computers, telecommunications equipment, aerospace, and similar electronics.
- b) Feeder effects -- MITI encouraged those industries that produced materials or components (ceramics, microelectronics)-- that were used by major Japanese industries.

- c) Economies of scale -- MITI encouraged the expansion of growth sectors in Japan to achieve economies of scale in industry, Government policy was to encourage investment in that industry;
- d) Importance to the economy -- MITI favoured industries whose output was essential to the Japanese economy.

During the 1950's and 1960's, iron and steel, aircraft, automobiles, electric power, petrochemicals, nonferrous metals, machinery, and shipbuilding were among the industries selected by MITI as "target industries". In the 1970's and early 1980's, MITI selected advanced technology industries for targeting, such as computers, advanced machine tools, and microelectronics (Anderson, 1984).

The criteria for a Japanese industry sector to be designated as "targeted" by MITI changed over time. Targeted assistance by MITI in the 1950's and 1960's was focused on the development of production processes of a given basic industry with "feeder" and "linkage" or inter-industry effects. For example, advances in the Japanese chemical industry provided inputs for microelectronic sectors which in turn provided the basis for consumer electronic growth. Starting in the 1970s, MITI directed targeted assistance toward industry sectors with potential for scientific and technological advancement for which there was export potential and from the late 1970s to the mid-1980's, to industrial sectors that

could make a contribution across the industrial base of Japan and were in demand in world markets (SHC, 1988).

Since the mid-1980's, MITI's selection of "target industries" has become much more muted because the overall growth of Japanese private sector firms made these firms less willing to accept special government assistance when the price for such assistance was an obligation to follow "rules" set forth by the Government (Japan Society for the Promotion of Science, 1988).

As noted, MITI was the principal Japanese government agency which selected industry sectors for targeting. However, other Japanese government agencies, notably the Science and Technology Agency have, at times played some role in the selection process. During the period from 1971 to the mid-1980's, a total of twelve industry sectors were selected in Japan as "target industries", MITI selected eleven of these, while the Science and Technology Agency selected the aerospace industry as a "target industry" in 1985 (SHC, 1988).

MITI's influence in the "target industry" selection process was derived from its other important role, that of providing financing to private sector firms. Between 1971 and the mid-1980's, the Industrial Finance Division of the Industrial Policy Bureau of MITI selected industry sectors for low-interest loans through the MOF's Fiscal Investment and Loan Programme (FILP).

MITI's low interest loans, however, were provided to private sector firms on the condition that the firms would follow MITI's investment guidance⁽³⁾ (Inose, 1979; Johnson, 1982).

MITI "guided" firms to invest such that each firm in a market expanded its production capacity in proportion to its current market share -- no firm was to make an investment so large that it would destabilize the market. The policy was effective in encouraging competition for market share while reducing the risk of excessive investment. These MITI policies, in fact, promoted the aggressive expansion of capacity necessary to increase the productive efficiency and output of Japanese firms with increasing domestic sales and exports. In the light of these activities, a brief discourse on economic theory may be useful to understand fully MITI's role in Japanese economic growth (Anderson, 1984).

Economic theory maintains that market share competition such as administrated by MITI, cannot be sustained over long periods because of price competition among firms. MITI's solution to possible price competition among Japanese firms was to establish cartels along lines of economic sectors or among firms engaged in the manufacture of similar products accompanied by price controls. As a result "administered prices" were established by MITI in steel, chemical, microelectronic, optics, consumer electronic and other sectors of the Japanese economy. MITI's control of the

allocation of market shares combined with price controls successfully and completely overcome the logical result of "market share" competition postulated in economic theory, that of ruthless price competition among firms and consequently a lack of stability in sectors of the economy (SIA, 1983; Shimo, 1986).

MITI's selection of "target industries" in Japan and its creation of a comparative advantage for these industries in world markets changed gradually during the last two decades from an emphasis on the industrial processes which could be enhanced by the use of advanced technologies and scale of production, to industry sectors producing advanced technology products. The recognition by MITI of the importance of advanced technology products rather than advanced technology processes for Japanese economic growth via increased exports developed gradually, and was "officially" recognized in the Japanese government's visions for the 1980's (Shimo, 1986).

Although specific industries had not been designated in visions for the 1980's as targets, a number of industries were specified as meeting the criteria for potentially large exports and income generated from such exports. Microelectronics, computers, aircraft and robotics were pointed out as the obvious industries representative of advanced technology products. MITI has announced, since 1980, a total of ten industry sectors in Japan and provided these with funding assistance with the common

aim of leading the world markets in advanced technology products (Shimo, 1986).

The emphasis on the need to develop advanced technology products officially recognized in the visions for 1980, was initially identified in 1977 in a report by the Japanese Council for Science and Technology which pointed out the importance of advanced technology products for the Japanese economy (SHC, 1988).

The Japanese Seven Year Socio-Economic Plan, published two years later in 1979, expressed the hope that innovation in advanced technology sectors would result in advanced technology products and would provide the key to economic growth in the 1980s. According to this Plan advanced technology processes and products would:

- a. Ensure stable growth in the Japanese economy;
- b. Relieve energy restrictions in Japan;
- c. Make Japanese industry more knowledge-intensive, more productive and more profitable;
- d. Enlarge Japan's role in international relations; and
- e. Permit more effective use of land in Japan.

The emphasis on science and technology issues has been repeated in several policy statements by MITI since 1980.⁽⁴⁾ In 1983, the economic policy plan prepared by MITI and other Japanese government agencies entitled "Outlook and Government Outline for the 80s" was adopted by the Nakasone cabinet and clearly emphasized

the Japanese government's programme to advance science and technology in Japan (ITC, 1983; Shimo, 1986).

The latest economic plan for Japan, that of Prime Minister Noboro Takeshita, was released on April 1, 1988, and identifies the goals of Japanese economy through to March 31, 1993, with the emphasis on the advancement of science and technology. This plan, the eleventh in the postwar period, with a theme of "Japan Living Together with the World," was prepared by MITI in close collaboration with the Economic Council -- a group of 27 academics, industry leaders and labour representatives. The group was headed by Gaishi Hiraiwa, the chairman of Tokyo Electric Power Co., Inc., one of the best known advocates for advanced technology adoption in Japanese industries (SHC, 1988).

In summary, in the last three decades MITI's role in the selection of industrial sectors in Japan for growth and the provision of government support of various kinds has been of cardinal importance in the planning and execution of the Japanese government's science and technology policies.

The very rapid growth of the Japanese economy in the 1980's has limited the influence of MITI's activities, because Japanese private sector firms need not depend on the Japanese government for financial assistance or policies which would enhance the export sales of Japanese firms. While MITI's ability to direct

the Japanese economy via "administrative guidance" has been reduced, MITI's willingness to provide such direction has not been diminished (SHC, 1988).

12.3.3 The Ministry of Finance (MOF)

The Japanese MOF influences science, technology and industrial policies in Japan through its control of financial institutions, including the Japanese government's own financial agencies. The MOF is the principal agency which determines the allocation of Japan's budgets, and therefore exerts considerable influence over the Japanese government's assistance to private industry sectors. The MOF also participates in the determination on which industrial activities and industrial sectors in Japan will be encouraged by special Japanese tax measures. It is however, in the Japanese budget allocations that the MOF has its strongest influence on Japanese science and technology policies.

The Japanese government budget consists of two parts: the General Account budget consisting of funds obtained through taxes, and payments to the Japanese Treasury, and the Fiscal Investment and Loan Program (FILP), a capital budget, consisting of funds obtained through the Japanese postal savings system and from pension funds. Together, the two budgets represent an increasing proportion of the total Japanese GNP ranging from 20 to 30 percent in the last decade.

The FILP component provides a number of Japanese institutions with lending and investment authority including the Japan Development Bank (JDB) and the Small Business Finance Corporation (SBFC). Approximately 14 percent of corporate financing in Japan originated in Japanese government financial institutions in the 1980's. Approximately 26 percent of the annual FILP budget is directed by the MOF to industrial policymaking banks in Japan such as the Export-Import Bank of Japan (JEXIM).

12.4 JAPANESE GOVERNMENT POLICY TOOLS TO ADVANCE SCIENCE, TECHNOLOGY AND INDUSTRY

The Japanese government, with MITI as the principal agency for policy execution, has used a large number of policies to advance science, technology and industry sectors. The many policy tools may be conveniently categorized into two groups:

- a) Those policies used against foreign competition, which allow Japanese industrial sectors and firms to operate in Japan without the need to face competition from abroad in Japanese domestic markets; and
- b) Those policies which provide Japanese government support to the industry sectors and firms in Japan, in order to allow them to compete in domestic markets, i.e., in Japan, but equally

important, to facilitate their ability to compete in the international market place.

Table 12.4 illustrates the policy tools used by the Japanese government.

The objective of Japanese government policies in both categories is the same, namely to provide Japanese industry with opportunities to operate and grow in both domestic and international markets without interference or competition from foreign firms (Anderson, 1984; SHC, 1988). In economic terms both types of policies aim at establishing for Japanese industry comparative advantage over firms and sectors of the economy of other nations. In this respect, these policies in fact violate the fundamental principles for economic growth and development prescribed by classical economic theory. The fact that Japanese government policies have not adhered to the prescribed principles of economic theory in order to achieve economic growth cannot be questioned, it is well documented and known. It is also a fact that these two types of Japanese policies have resulted in unprecedented economic growth in Japan. There are, however, some differences between these two groups of policies, both directed to achieve comparative advantage for Japanese industry sectors (Curren, 1982; SHC, 1988).

The anti-foreign competition policies are used by the Japanese government, as a rule, only during periods when an industry sector

TABLE 12.4

**Tools-Policies Used by the Japanese Government
to Advance Japanese Industry Sectors
in Domestic and International Markets**

<u>Tools-Policies Used Against Foreign Competition</u>	<u>Tools-Policies Used to Support Japanese Industry in Domestic and Inter- national Markets</u>
a. home-market protection	a. direct government grants
b. barriers to trade	b. government sponsored scientific and R&D activities
c. closed government procurement	c. loans to private sector R&D
d. administrative guidance	d. cooperative scientific and R&D activities
e. restrictions to foreign investment	e. control over technological licenses
	f. tax policies
	g. export incentives
	h. antitrust exemptions

Source: SHC, 1988.

is in its early stages of technological development. During this period the Japanese technology may be inferior to that available to foreign firms and the output of Japanese sectors or firms may be relatively small and therefore production costs relatively high. Many of the Japanese policies of this type (used against foreign competition) are discontinued when Japanese technology is equal to that used by foreign firms and when output has reached the volume sufficient to enable the Japanese to construct and operate large scale production facilities with scales of production adequate to significantly lower operating costs (ITC, 1983; Shimo, 1986).

The anti-foreign competition policies are visible and may violate international agreements in trade, investment, patents, etc. Such policies, may be subject to punitive reactions by other nations and therefore are used by the Japanese government with considerable caution.

Japanese government policies to support Japanese industry in domestic and international markets are less controversial and may be similar to the policies of other nations. These policies are less likely to result in punitive reactions by foreign nations.

The anti-foreign competition policies as used by the Japanese government are unique in that few other nations have attempted the use of such anti-foreign policies to the same extent as the

Japanese. Conversely, most nations have used at least some of the policies employed by the Japanese to support their domestic and international markets.

12.4.1 Anti-Foreign Competition Policies by the Japanese Government

The Japanese government has used some five different types of policies to protect the economy or firms from foreign competition:

- a. home-market protection;
- b. formal barriers to trade;
- c. closed government procurement;
- d. administrative guidance; and
- e. restrictions to foreign direct investment.

12.4.1.1 Home-market Protection

Home-market protection was an important policy used by the Japanese until the mid-1960's. Such policies took the form of complete import controls through foreign-exchange allocation. Essentially those policies required all purchases by industry and consumers to be made for goods and services provided by Japanese firms unless a product was not available from Japanese sources. The specific mechanism used to enforce these policies consisted of quotas on many products until the early 1970's; high tariffs on some items until 1973; limits on direct foreign investment in

Japan until 1973; and closed government procurement until the mid-1980's.

Most Japanese advanced technology industries were protected by severe tariffs, quotas, and investment restrictions until 1976. Throughout this period, Japan also used a variety of nontariff barriers to trade e.g., rigorous inspection of foreign goods at port; procedures necessary to obtain certification that foreign goods meet Japanese standards, shipment declarations, safeguard health standards, etc. (Johnson, 1982; ITC, 1983).

12.4.1.2 Formal Barriers to Trade

One of the most effective mechanisms used by Japan to protect the domestic markets in the 1950's was the law which allowed MITI to allocate foreign exchange for import purchases. The Foreign Exchange and Foreign Trade Control Law was enacted in 1950 and provided MITI with a very effective means of controlling imports of goods and technology. It also allowed MITI to direct foreign exchange to Japanese industry sectors and activities considered vital to the Japanese economy. Foreign exchange allocation was also used to support the value of the yen in international currency markets (Shimo, 1986).

In the early 1950's, Japan also used so-called "Link trading" to control imports. Under the link trading system Japanese

exporters of designated products were authorized to import various types of goods. During this period foreign exchange and import restrictions were very restrictive and certain imported goods were in very short supply in Japan. Imported foreign products under the Link System were therefore effectively controlled. It also must be added that the link system provided a significant incentive to increase Japanese exports (Johnson, 1982; SHC, 1988).

During the 1950's and 1960's, only industrial equipment and machinery which were not produced in Japan, were allowed to be imported. Equipment and machinery which were available from Japanese sources regardless of its quality or technology, could not be purchased from foreign sources.

Japanese government policies to control imports were gradually allowed to expire beginning with a plan to liberalize some of Japan's imports in the mid-1960's. The Japanese government, however, maintained control over specific imports to protect targeted industries or industries considered crucial to Japan's economic development by requiring cumbersome license review processes for such imports until the mid-1970's. Only in the late 1970's did the Japanese government withdraw most of the barriers to imports. As can be seen in Table 12.5, Japan's tariff rates in 1987 were comparable with those of the U.S. and EC nations.

12.4.1.3 Nontariff Barriers

The use of various nontariff barriers to imports was practised extensively by the Japanese government during the 1950's, 1960's and 1970's. These consisted of: demands for excessive documentation, rigid adherence to customs regulations, frequent and lengthy inspection of imported products upon arrival in Japan, enforcement of design rather than performance standards, changes in standard regulations and many others. Some of these barriers, particularly for advanced technology products, such as microelectronic devices which compete with Japanese products, remain in place at the present time (ITC, 1983; English and Brown, 1984).

12.4.1.4 Closed Government Procurement

Purchases of goods and services from Japanese firms by Japanese government departments and agencies was another effective policy against imports. There are 115 public corporations in Japan, with a combined budget totalling one-half of the Japanese government's annual General Account budget. During the 1950's, 1960, and even 1970's, these corporations followed explicit "buy Japan" policies, which excluded bids from foreign firms. In the 1980's more informal barriers have served to limit foreign participation in Japanese government contracts, such as long-time ties between Ministries and their domestic suppliers (SHC, 1988).

TABLE 12.5

Tariffs in Japan, the United States, and the
European Community, by Specified Items, 1987
(Percent)

Item	Japan	United States	European Community
Autos	-	2.8%	10.6% to 21.3%
Parts of autos	-	1.3% to 16.3%	5.3% to 12.3%
Trucks	-	4.0% to 25.0%	7.0% to 22.0%
Computer mainframes	4.9%	4.7%	5.94%
Computer peripherals	6.0%	4.7%	11.62%
Parts for computers	4.9%	4.9%	5.3% to 8.9%
Semiconductors	4.2%	4.2%	17.0%
Optic cables	8.1%	9.3%	16.3%
Machine tools	-	5.0% to 6.0%	2.0% to 9.0%

Source: MITI, 1988.

12.4.1.5 Administrative Guidance

During the 1960's and 1970's, specific administration guidance by the Japanese government's departments and agencies was frequently used to require the purchase of domestically produced goods and services.

The specific administrative guidance used essentially consisted of instructions issued by Japanese government departments and agencies to private sector firms falling within their jurisdiction. These instructions included explicit directives, requests and warnings, to purchase goods and services from specific (Japanese) firms (SHC, 1988).

12.4.1.6 Restrictions to Foreign Direct Investment

Restrictions on direct foreign investment were used from the 1950's to the late 1970's to protect Japanese domestic producers from foreign competition in Japan (Johnson, 1982).

The entry of foreign firms into Japan during the 1950's and early 1960's was essentially prohibited under the Foreign Investment Law of 1950 which allowed the Japanese government to regulate the impacts of foreign capital and technology on Japanese industry sectors. In 1967, the Japanese government allowed for up to one-half foreign ownership in a number of Japanese industry

sectors. Further allowances for direct foreign investment in Japan were implemented in 1970 and 1983 although these were closely monitored by MITI (SHC, 1988).

12.4.2 Japanese Domestic Industry Support Policies

The Japanese government has exercised a set of comprehensive policies to support industry sectors in domestic and international markets. Principal among these are:

- a. direct government grants;
- b. government-sponsored research and development activities;
- c. loans to private sector research and development;
- d. cooperative scientific and research and development activities;
- e. control over technological licenses;
- f. tax policies;
- g. export incentives; and
- h. antitrust exemptions.

A large number of these policies have been enacted to foster the advancement of science and technology in Japan as well as to ensure that research and development activities are undertaken by Japanese firms with appropriate levels of funding.

The three specific policies used by the Japanese Government to foster the advancement of science and technology consisted of tax

incentives for research and development, research and development grants and preferential financing for research and development projects.

12.4.2.1 Direct Grants for Research and Development

Japanese government departments and agencies with MITI as the principal government agency, have provided direct grants for research and development activities to Japanese research institutions, academia and private firms. MITI's annual funding for this purpose in the last three decades averaged about 10 to 15 percent of the total Japanese government's expenditure for research and development. In 1987, MITI funded about 12 percent of the Japanese government's total research budget, or about \$700 million.

12.4.2.2 Government Sponsored R&D Projects

Japanese government funding of special research has been an important government policy tool in the science and technology area. Two principal objectives have guided such projects: a) to diffuse technology and b) to overcome technological bottlenecks.

There are two categories of government-funded R&D in Japan: those that are funded entirely by the government and those which are funded by conditional loans to private sector firms.

In the case of research and development activities that are completely government funded, the government owns the results of the research and development effort. The results of these research and development activities are available to all interested parties for a fee. These types of research and development activities are conducted, either by National Research Laboratories, operating under the Agency of Industrial Science and Technology (AIST) within MITI, or Japanese government contracts with private research institutes or firms to conduct research in a specified area of science, technology or product law. The government funds such research and development projects by either providing unconditional grants, referred to as consignment, or "itakuhi" payments; or provides funds through so-called success-conditional loans or "hojokin" loans. The hojokin loans need to be repaid only if commercial production results from the research effort.

Itakuhi, payments and hojokin loans are the two principal alternatives for the government's funding of research and development performed by the Japanese private sector.

12.4.2.3 Cooperative Research Associations

Cooperative research associations of firms aimed at undertaking research and development funded by the Japanese government under the itakuhi or hojokin loan schemes are widely used in Japan.

A significant number of cooperative research associations such as the Electric Car Research Association have been established for specific research projects while others are established to undertake research in a specific industry sector. As of 1987 there were about 30 cooperative research associations operating in Japan.

12.4.2.4 Control Over Technology Licensing

The Japanese government used extensively the Foreign Investment Law of 1950 as a control over technology licensing from foreign firms, during the 1950's and 1960's. Under this Law, firms were required to submit proposed international transactions to MITI for approval which were granted or refused in concert with MITI's plans and programmes. Since 1973 government controls in this area have been marginal.

12.4.2.5 Special Tax Measures for R&D

Special tax measures in Japan have been enacted from time to time during the last three decades to encourage research and development and the diffusion of technology in Japan. The current tax measure in force, enacted in 1986, provides tax credit of 25 percent of any year-to-year increase in research and development expenditures over the previous year. In 1987, Japanese corpora -

tions realized tax savings of about \$122 million using this tax credit.

12.4.2.6 Export Incentives

During the 1950's, 1960's, and 1970's the government used various export incentives. These included various tax rebates for exports, export cartels, the already discussed "Link system" and regulations which permitted Japanese exporters to retain a percentage of the foreign exchange generated from their exports. There are no significant export incentives in force as of 1989.

12.4.2.7 Antitrust Exemptions

As presented elsewhere in this volume, Japanese government departments and agencies in the 1950's and 1960's exercised administrative guidance which essentially established quotas for production as well as price levels. Such "guidance cartels" functioned through MITI notifying either individual producers or an industry association of the desired production levels for domestic consumption and exports as well as prices to be charged. Guidance cartels provided a flexible mechanism to limit excess production of certain products in Japan and therefore to maintain price stability in export markets. They also effectively removed any and all antitrust laws existing in Japan.

12 5 JAPANESE GOVERNMENT POLICIES FOR ADVANCED TECHNOLOGY SECTORS

Japanese government policies to foster the three advanced technology sectors follow the pattern used for the general advancement of science, technology and industry in Japan.

There are, however, some differences in the government's policies to direct the advanced technology sectors brought about by the presence of international markets in which Japan competes as compared to other industry sectors in Japan.

12.5.1 Microelectronics Sector

The Japanese government has targeted the microelectronic industry for growth and development since the early 1960's. Government attempts to establish comparative advantage for its microelectronics sector was based on the expectations of increased world-wide demand for these products and on the assumption that products in this sector would provide components for the Japanese consumer electronic, robot, and machine tools industries, the automotive sector, the instrument market, and other sectors in Japan. The Japanese authorities have been proved correct in this assumption (Kikuchi, 1983; Kodama, 1986).

Until 1974, high tariffs, restrictive quotas, and investment restrictions protected the Japanese microelectronic product sector

from imports, and allowed competition-free development of the microelectronics industry in Japan. Since 1974, the main thrust of Japanese targeting efforts in the microelectronics industry has been Japanese government-funded cooperative research and development projects (MITI, 1980; SIA, 1983).

The success of the Fourth Generation Computer Development Project proposed by MITI in 1974 is illustrative of early Japanese cooperative research policies. This project focused on the development of large-scale integrated circuit development in Japan comparable to those used by IBM in the U.S., the dominant computer manufacturer in the world. In 1976, the Very Large Scale Integration (VLSI) project was organized in Japan by MITI as a component of the Fourth Generation Computer Development Project. MITI obtained cooperation in the VLSI project essentially from all Japanese microelectronics firms. Six Japanese companies--Hitachi, Fujitsu, Mitsubishi Electric, NEC, and Toshiba -- were organized by MITI as the principal research team. At the same time, a parallel project was undertaken by a backup team of three major Japanese firms: Hitachi, Fujitsu, and Oki. Both teams were successful, and one of the products that resulted from the Japanese VLSI project was the 64K RAM chip, the leading micro-electronic memory device in the world in terms of sales from 1979 to 1986. The research budget for the VLSI project including company contributions for both teams, was \$325 million, with MITI

providing \$136 million in the form of success-conditional loans (SIA, 1983).

Japan's Fifth General Computer Project (5G) was initiated in 1981, at the conclusion of the very successful VLSI project.

The 5G project is a ten-year effort funded jointly by Japanese government and industry with a total budget of about \$530 million. The principal goal of the 5G project was the development of a new generation computer with artificial intelligence (Wheeler, et al., 1982).

There were two important characteristics of this project:

- a) International involvement was a stated policy of the project, thus marking a change in policy direction by MITI.
- b) The project was oriented toward basic rather than applied research.

The project was conducted by an association of eight computer and microelectronics companies and two national laboratories (Table 12.6). A central facility for conducting the research and development was established in 1982 as the Institute for New Generation Computer Technology (ICOT).

Related microelectronic research was organized by MITI under the Optoelectronics Integrated Circuits (OEIC) Project in 1983 and under the New Function Elements Project in 1984, which were

TABLE 12.6

Participants in the Fifth
Generation Computer Project

Industry

Fujitsu Ltd.

Hitachi Ltd.

Matsushita Electric Industrial Company

NEC Corporation

Oki Electric Industry Company

Sharp Company

Toshiba Corporation

Government

Electrotechnical Laboratory of the Agency of Industrial
Science and Technology (MITI)

Nippon Telegraph and Telephone Public Corporation

Source: SHC, 1988.

partially funded by government and industry and were directed by MITI (Table 12.7).

The OEIC effort involves nine Japanese companies and a central research laboratory operated by the Fujitsu Corporation. The budget for the OEIC project is approximately \$98 million (Weinstein, et al., 1984).

The New Function Elements Project is a ten-year programme, funded at about \$114 million, with 11 participating companies collaborating through the Research and Development Association for Future Electron Devices (FED). There are three areas of concentration: superlattice devices, three-dimensional IC's, and fortified IC's.

The most recent example of government funded research projects is the New Function Semiconductor Research Project (NFSRP) established in 1985 in which ten Japanese microelectronics firms participate -- Fujitsu, Hitachi, Matsushita, NEC, Oki, Sanyo, Sharp, Sumitomo, and Toshiba with the Nippon Telephone and Telegraph Corporation (NTT) acting as coordinator (SHC, 1988). These ten firms, under the leadership of MITI, have established a comparative association explicitly for the purpose of undertaking the required research for the NFSRP.

TABLE 12.7

New Functions Elements Project - 1980-1990

MITI Funds

Research and Development
Association for
Future Electron Devices

Members	Fujitsu Hitachi Sony	Matsushita Mitsubishi NEC Sanyo Sharp Toshiba	Hitachi Mitsubishi Toshiba
Project	Superlattice Devices	3 Dimensional IC's	Fortified IC's
Goals	Develop lamination techniques for building multiple-layered structures in which each layer is one atom thick; develop techniques for reducing cathode-to-anode distance within individual semiconductors to within 5000 Angstroms	Develop methods for incorporating IC elements into chips in layers to increase density of elements by 40-50 times	Develop element, mounting integration and evaluation technologies with the ultimate aim of producing highly integrated IC's, IC's capable of withstanding extremes of heat and radiation

Source: U.S. Embassy, Tokyo, May 1982, presented in English; and Brown, "Japanese National Actions in IT," European Communities, July 1984; and the Research and Development Association for Future Electron Devices," presented in JST News, Volume 3, Number 4, August 1984.

The NFSRP cooperative project differs from all others in that the NTT plays the crucial role of research coordination for the project. The NTT has often conducted research with its "family" of firms or shares the results of its own research with the "family," (NEC, Fujitsu, Hitachi and Oki). It is very unusual for the NTT to collaborate with other Japanese firms or to share research results. The NFSRP project is an exception, and indicates the importance the government places on cooperative research projects in the microelectronic sector. The NTT's own experience and capabilities in the microelectronics sector significantly enhances NFSRP projects (SHC, 1988).

The NTT has four extensive research laboratories with employment of over 3000. These NTT facilities in 1988 were conducting research in wide areas of the microelectronic industry, electronic switching systems, memories, semiconductor integrated circuits and components, data processing, systems, and optoelectronics. Concurrently other internal NTT research projects were underway in 1988 to develop a very high-speed computer for scientific purposes and to develop optical measurement and control devices. These areas of research essentially represent all of the advances in microelectronic technology as of 1989.

The combined multiyear funding from the Japanese government and industry for all four microelectronic cooperative research and development projects is about \$1.3 billion.

A recent OTA Report underscores three distinct features of the Japanese approach to cooperative research and development:

Compared with other countries, Japan's approach to aid for electronics is unique in at least three ways: (1) government-supported programs are multiple but carefully coordinated with one another; (2) they are oriented toward facilitating the activities of industry, rather than telling industry what to do; and (3) the time horizons are unusually long. The last point is critical: the 8- or 10-year planning horizons for many current Japanese R&D projects--with every indication that, while projects will be adapted to evolving circumstances, continuity will be preserved--point to the depth of the government's commitment (Emphasis in original.) (OTA, 1983).

12.5.1.1 MITI'S Modus Operandi in the Microelectronics Sector: Cooperative Research Projects

MITI, as presented in previous sections, has the principal responsibility for implementing science and industry policies in Japan. Japan's industry structure consists of a number of permanent industry associations for major Japanese industry sectors and a large number of cooperative research associations are formed for specific research objectives (OTA, 1983).

MITI has the responsibility of directing both types of programmes and projects. In most nations such arrangements would not be allowed, because these violate basic anti-trust policies. In Japan's so-called Kidenho provisions, MITI has the authority to direct Japanese manufacturers to collaborate in undertaking the required research projects, in setting industrial standards, undertaking technology improvements, negotiating joint procure-

ments and directing other activities which in most other nations would represent a grave and explicit violation of antitrust laws. In Japan, however, as discussed in the following section, the Kidenho provisions "legalize" MITI's activities. MITI also has the complete confidence of the Japanese business community. As stated by Gregor (1984):

Vast amounts of information -- much of it quite sensitive-- are exchanged between MITI and industry through formal and informal channels. Although Japanese business leaders are normally very guarded about company information that might be used up by rival firms, they are willing routinely to divulge sensitive, proprietary information to MITI officials in full confidence that it will not be leaked or used against them. Obviously a strong sense of trust binds business leaders to MITI officials. To maintain that trust, MITI officials scrupulously observe neutrality, and work for the general interests of industry. Young MITI officials at the level of Division Director (kacho) and Deputy Division Director (kacho-hosa) from the Electronics Policy Division (Denshi Seiska-ka) and the Electronics and Electrical Machinery Division (Kikai Joho Sangyo Kyoku), stay in constant contact with key managers and leaders in the semiconductor industry. Usually, MITI's point of contact includes a technical specialist with engineering or technological expertise in semiconductors and an administrative official with legal or economic expertise, who is capable of framing issues or problems in terms of policy options.

Through such information collection, MITI has the capability to design and execute plans and programmes for industry sectors in accordance with overall Japanese industry policies.

MITI's leadership and activities can be readily seen from the following description prepared by a reporter of Asahi:

To challenge IBM, the VLSI research and development was begun, uniting government and the private sector. To carry out the research, the VLSI Technology Research Association was formed in April, 1976. Its membership consisted of five firms in two groups of domestic computer producers: Fujitsu-Hitachi-Mitsubishi and NEC-Toshiba Approximately 100 researchers from the member firms and MITI's Electronic Research Institute gathered at the [newly established] joint research institute. During the following four years, about 70 billion yen, including a government subsidy of 30 billion yen, was spent. The technology necessary to develop VLSI was developed and the Association disbanded

Initially, given the differing ideas concerning VLSI development among the member firms, decisions on the extent and nature of the joint research and which firm was to be responsible for which aspects of development, were extremely difficult to make. Interests of the member firms conflicted. And, even after the research topics were settled, there were the numerous problems to be expected in such a joint venture. Thus, six research rooms were created, each headed by a leader from one of the five member firms and one headed by a person from the Electronics Research Institute. During the first year, the walls between these rooms were thick. Participants tried to prevent others from finding out the progress being made in each room. "In extreme cases, the entrance was barricaded to prevent other researchers from coming in," recalls Nebashi [of MITI], who headed the joint research institute.

Nebashi did his best to eliminate the egoism of the member firms and to create the harmony among researchers necessary for joint research. In the evenings he went to the rooms and listened to the researchers' opinions and any dissatisfactions they had. At times, he drank sake with the researchers. . . . The monthly meetings, attended by senior officers of the member firms, were intentionally held at the joint research institute The purpose was to let these officers become familiar with the projects and boost the morale of the researchers. In time, tennis and golf clubs were organized among the researchers . . . and the walls of secrecy dividing the research rooms were gradually removed (Yamamura, 1986).

In summary, the Japanese government policies to advance the Japanese microelectronics industry have included:

- a) General agreement on industry-wide goals between MITI and industry;
- b) Formulation of Visions for microelectronic product development and its integration within a comprehensive industrial policy;
- c) Coordination of, and subsidies for, large-scale, national research projects of high priority for the industry as a whole;
- d) A rough division of labour in research effort between government laboratories (basic research with high costs and risks) and industrial laboratories (applied and commercially oriented research);
- e) Extensive information flow and communication exchange between government and industry; elaborate channels for on-going dialogue;
- f) Special tax incentives
 - i) Accelerated depreciation
 - ii) Research and development tax credits
 - iii) Deferrals
 - iv) Special reserve funds to protect against losses
- g) Special financing and credit for small-medium industries
- h) Japan Development Bank (JDB) and other public and semi-public financial institution loans;
- i) Determination of interest rates; general monetary and fiscal policies;

- j) Nippon Telephone and Telegraph Co. (NTT) and other public agency procurements;
- k) Indirect measures to boost aggregate growth rates and hence semiconductor demand;

The results of the Japanese government's policies to achieve comparative advantage for the microelectronics industry in Japan can only be described as outstanding.

In a period of a decade or so Japan has become the leading manufacturer of microelectronic products with more than one-half of all world microelectronic devices produced in Japan. Japanese achievements in the microelectronic sector can be best understood with a very brief account of the market shares and trends in the leading microelectronic product, that of "memories." In 1975 the U.S. produced over 85 percent of the total memory devices in the world. In 1980, the U.S. produced over 70 percent of memories and Japan about 25 percent. In order to dominate the world's memory device market, Japanese electronic firms rapidly expanded their production capacity (in the face of very slow demand) and suffered losses estimated at \$4 billion between 1979 and 1987. However in 1987 the Japanese share of memory devices had increased to 80 percent and U.S. share had fallen to 19 percent.

As the result of the increased Japanese production capacity between 1979 and 1987, the prices of these devices were reduced below break even level in world markets, and a number of U.S.

memory device producers stopped the manufacture of these products. More important, the U.S. firms also reduced their research and development efforts, related to technology advances in memory devices. The reduction in research and development activities by the U.S. firms occurred at a time (from 1982 to the present) when technological advances in memories made it possible to replace 64K memories with 256K memories only to increase the "size" further to one megabit memories in 1987. The advanced memories are used in most computers and comprise about 25 percent of the computer cost. With the demand for computers increasing significantly in the 1986-1989 period there occurred a dire shortage of advanced memory devices, which only Japanese firms were able to satisfy. The prices for megabit memories charged by the Japanese increased and in 1988 alone the prices increased by a factor of four or five. Japanese firms have the advanced "memory" world market essentially alone as the U.S. microelectronic firms manufacture only a negligible quantity of these advanced products (SBC, 1986 and 1988).

These developments are summarized in a recent article (Hector, 1988):

Armed with mountains of capital, the Japanese added DRAM capacity steadily throughout the 1970s. By the 1985-86 slump they had helped create a huge oversupply. To minimize losses on capital invested in factories, Japanese producers flooded the market with DRAMs and to a lesser extent with other commodity chips with EPROMs (erasable, programmable, read-only memories). While this behavior was perfectly rational for the Japanese, it led to cries to dumping in the

U.S., where domestic manufacturers lost more than \$2 billion battling to keep market share.

By operating their plants at full capacity an average of 130 hours a week, Japanese producers achieve significant economies on large production lines. In some cases their costs have been 30% or more below U.S. manufacturers. Even so, security analysts estimate that they lost some \$4 billion in 1985-86. That experience alone should help head off future price wars--especially since the highflying yen has knocked the Japanese out of their position as the industry's low-cost producer. They now lag behind competitors in Korea and other Asian nations that have not been so hard hit by rising currencies. Despite the good news, most U.S. chipmakers aren't comfortable enough to go charging back into the DRAM market.

12.5.2 Japanese Government Policies to Advance the Machine Tools Sector

As in the case of the microelectronics industry, MITI has exerted a strong influence over the direction of Japanese machine tool development through low-interest loans, the approval of licensing agreements for the sale or acquisition of new technology, and the control of international trade flows. MITI has encouraged heavy investment in machine tools and the willingness of Japanese banks to finance machine tool firms has enhanced the ability of Japanese firms to undertake research and development and long-term capital expansions and investments in the machine tool/robotics sector far beyond that undertaken in the U.S. or Germany (Baranson, 1983; MITI, 1985; Aron, 1982).

Government-sponsored R&D in the machine tools sector is prevalent in Japan with a high level of cooperation between Japanese government and industry.

The involvement of the Japanese government in the machine tool sector dates back to the 1950's and 1960's when it began using a variety of policies to develop the industry. These measures included legislation to provide the legal basis for the Japanese government's planned rationalization and promotion of the industry, the formation and subsidization of industry associations, the provision of antitrust immunity for interfirm activities undertaken to achieve the Japanese government's planned objectives, temporary bans on imports of certain foreign machinery to stimulate domestic production, Japanese government-sponsored research and development, low-interest loans, tax incentives, favourable depreciation schedules, etc. (Crossley, 1979; Baranson, 1983).

In particular, three laws were enacted and implemented under Cabinet Enforcement Orders which have directly helped the development of the Japanese machine tool industry as reported by MITI (1986):

Extraordinary Measures Law for Promotion of the Machinery Industry (June 1956)

This law laid the groundwork for the promotion of the machine tool industry. It directed MITI to prepare a basic rationalization plan; authorized MITI to instruct industry to take "concerted actions" such as restricting the kinds of

products to be manufactured, setting production and export quotas, arranging for joint purchases of parts and materials, restructuring industry, establishing price guidelines, etc. and provided antitrust immunity for interfirm activities performed under MITI's instructions. The Cabinet Enforcement Order for this law (July 20, 1956) selected the metalcutting machine tool business for promotion and authorized necessary funds or loans (MITI, 1986).

Extraordinary Measures Law for Promotion of Specific Electronic Industries and Machinery Industries (1971)

This new law replaced the expiring 1956 law. It empowered MITI to 1) adopt rationalization/development plans for designated industries, including the NC and CNC metal-cutting and metal-forming machine tools as types of machinery to be promoted; 2) conferred upon MITI the authority to instruct industry to engage in cooperative activity under immunity from antitrust prosecution; and 3) committed the government to provide the necessary financial assistance, i.e., directed MITI to ensure that the funding required to reach development plan goals would be available (MITI, 1986).

The Extraordinary Measures Law for the Promotion of Specific Machinery and Information Industries (1978)

This law replaced the 1971 law. In content it was almost identical, except that the 1978 law includes the promotion of the software industry. As such, the 1978 law promotes the introduction of modern production techniques and rationalization of production. The Cabinet Enforcement Orders of September 1978 specify for promotion several types of CNC metal-cutting machine tools, as well as the most advanced types of metal-forming machine tools (MITI, 1986).

The 1978 Extraordinary Measures Law was in effect until 1987. It required MITI to prepare development plans (known as "Elevation Plans") for selected industries which used machine tools and robots extensively. The law empowered MITI to direct firms to engage in "concerted action," such as collaborating on production volume, research and development, specialization, standardization,

etc., and exempted such interfirm cooperative activity from antitrust prosecution (ITC, 1983; Baranson, 1983).

The 1982 Export and Import Trading Law, had a direct impact on the Japanese machine tool industry and provided a legal foundation for cooperative activity by allowing antitrust immunity for interfirm cooperative activities (approved by MITI) involving machine tool products designated for export. In the event that collaborating firms failed to achieve the export volumes of the Export and Import Trading Law for machine tools, MITI had the authority to force cartelization of export trading of the machine tool firms. In such cases, MITI had the authority to prescribe not only export prices, but also product design and quantity to be exported (MITI, 1983).

Under these laws, and on the direction of MITI, the Japan Machine Tool Builders Association (JMTBA) arranged and coordinated the machine tool industry's compliance with Japanese government objectives, in cartel fashion, i.e., through three industry-wide agreements that required member firms to: (a) concentrate production in machines which constituted more than 5 percent of their market and more than 20 percent of their production; (b) observe monthly production guidelines for specific types of machine tools; (c) reject orders for machine tools not authorized for production; (d) achieve overall product targets by rearranging production among member firms, but without increasing the number of firms

manufacturing each major type of machine tool; (e) share technology acquired from foreign sources and gain "group approval" for prospective technical links with foreign firms; and (f) notify the JMTBA of intent to market new machine tool products in order to obtain manufacturing approval by members of the association (Baranson, 1982; ITC, 1983).

The Japanese government also provided financial assistance to the machine tool industry directly, in the form of subsidies and loans, and indirectly through loan guarantees. During the 1957-1978 period, MITI implemented eight Elevation Plans for the machine tool industry, with a total financial commitment of over \$804 million to promote their development. Of that amount, \$444 million was spent between 1978 and 1982, mainly for the promotion of the machine tool sector (MITI, 1983; ITC, 1986).

Indirect MITI assistance since 1978 has enabled the Japanese machine tool industry to obtain \$114 million in loans at "preferred" interest rates from the Japan Development Bank (JDB) and the Small Business Financing Corporation (SBFC), of which over \$89 million were provided since 1978. Financing was also provided for certain foreign sales by the Japan Export-Import Bank (JEIB) (MITI, 1986).

Tax reforms were adopted by the Japanese government in 1984 to "promote modernization of medium and small-size enterprises."

Under the new tax law, medium and small-size businesses that fulfilled certain conditions were able to use either a special depreciation (30 percent of acquisition cost) or a special tax exemption (7 percent of acquisition cost) to purchase machine tools and robots (MITI, 1986).

Direct government grants to encourage and support research and development in the Japanese machine tool industry have been made during the 1970 to 1986 period by the Japan Research Development Corporation (JRDC), an arm of the Science and Technology Agency (STA), and by MITI's Agency for Industrial Science and Technology (AIST) (ITC, 1983; Baranson, 1983). It has been estimated that the value of these grants from all Japanese government sources has provided the Japanese machinery industry with \$35-45 million per year over the 1970-1986 period (MITI, 1986).

From 1974 to 1980 MITI was conducting a seven year, \$150 million research programme for the development of intelligent robots. Emphasis was placed on improving the sensory perception, language systems, and motion capabilities of advanced robots (MITI, 1983; MITI, 1986; Baranson, 1983).

For the purpose of promoting the utilization of robots by small and medium-size manufacturing firms, the Japan Robot Leasing Company, Ltd. (JAROL) was established in April 1980 at the encouragement of MITI. JAROL was established initially as a joint

venture between 24 private Japanese machine tool manufacturers and 10 insurance companies, and was capitalized at approximately \$500,000. In 1986, the JDB lent about \$7.8 million to JAROL, while the annual level of private sector funding was approximately \$5 million.

12.5.3 Advanced Materials Sectors in Japan

Japanese government policies in the advanced materials sectors focus on the advanced ceramics industry. Japan is already a world leader in advanced ceramics, accounting for about half of world production, and it dominates the electronic components business, particularly in integrated circuits packaging. Kyocera International alone has a 70 percent share in both the world and U.S. markets (valued at \$350 million and \$250 million, respectively) for advanced ceramics. Advanced ceramics markets in other electronic applications, such as ferrite heads in consumer electronics and computers are dominated by Japanese firms such as TDK Electronics and Murata Manufacturing (Kenney and Bowen, 1983).

In the electronic components business, Japanese leadership in advanced ceramics has been gained largely without direct or specific government assistance. Since engineering products, particularly heat engines for transportation and electric power generation, represent potentially larger but less certain applications, the role of the Japanese government is more

prominent in this area. There is an overall Japanese national effort to promote the development of new technologies in advanced ceramics including government organized and financed joint research and development programmes with universities and industry.

12.5.3.1 The Role of the Japanese Government in the Advanced Materials Sector

The Japanese government anticipates that the development of an advanced ceramics industry will make a major contribution to some of Japan's most important national goals:

- a) Being a natural resource poor nation, the use of advanced ceramics would enable Japan to substitute indigenous for imported raw materials and would also contribute to energy conservation, lowering its dependence on imported petroleum;
- b) Superiority in advanced electronic ceramics adds another advantage to their already strong electronics industries;
- c) Becoming the world leader in advanced engineering ceramics will result directly in sizable new exports of the products themselves and indirectly add to the value of automotive, machine tool, and -- perhaps -- aerospace exports.

Current Japanese government measures to support advanced ceramics must be understood in the context of a long tradition of government support for large-scale industrial technology. The Japanese National Research and Development Program (popularly known as the Large-Scale Project) was founded by the AIST in 1966 and involved a variety of high-technology projects.

This programme envisioned five major categories of future applications of advanced ceramics: electronic components, machine tools, machine parts, medical appliances, and coatings.

- a) Electronic Components. The application of advanced ceramics in the field of electronics will be further expanded, including materials for IC substrates, IC packages, condensers, varistors, piezoelectric elements, sensors, optical communications, and lasers.
- b) Machine Tools. Research is to continue on materials for new high performance cutting tools, in particular the development of titanium boride-based materials is being emphasized.
- c) Machine Parts. R&D is being accelerated for the application of non-oxide advanced ceramics to numerous machine parts.
- d) Medical Appliances. Advanced ceramics R&D is being focused on artificial joints and dental applications. Artificial bone structures are in the initial stages of research and development.
- e) Coatings. The coating of advanced ceramics on metal parts (metallic inner walls of engine cylinders and chemical pumps) improves heat resistance, lubrication and corrosion resistance of these parts. R&D to allow the multilayer coating of advanced ceramics on complicated parts, in order to prevent the separation of the coated ceramics layers, is also undertaken.

The centerpiece of current Japanese efforts to implement MITI's "Vision for the 1980's" and to promote new materials -- including advanced ceramics -- is the ten-year "Research and Development Project of Basic Technology for Future Industries" initiated by the AIST in 1981 (MITI, 1986). The focus of high performance advanced ceramics in this project is on the development of engineering applications for nuclear energy, aerospace, and heat engines, as opposed to electronic components.

In response to this initiative, Japanese industry in 1981 established a Fine Ceramics Technology Research Association representing Japanese companies involved in the development of advanced ceramics for nuclear fusion reactor walls and heat engines. In addition, an Association for New Metal and Compound Materials R&D, composed of major Japanese metal and chemical firms was established. In 1982, MITI established a Fine Ceramic Office in its Consumer Goods Industries Bureau to coordinate implementation of the vision in the ceramics area, to promote standardization of advanced ceramics technology, and to develop cooperation between producers and users of advanced ceramics (MITI, 1986; U.S. DOC, 1983).

In addition to these MITI-sponsored advanced ceramics programmes, the STA in 1981 initiated a five-year programme in materials science, which included advanced ceramics. In 1982, the Japanese Ministry of Education allocated about \$1 million to "New Investigations of Functional Ceramics." The Council for Science and Technology (an interagency group titularly chaired by the Japanese Prime Minister) is said to provide overall coordination for the efforts of the various ministries and R&D authorities (including the national laboratories).

Japanese government policies in the other areas of advanced materials is very limited, although MITI has prepared a long term research programme for composites (SHC, 1988).

12.6 CONCLUSIONS

Japanese success in advanced technology industries has occurred largely due to the Japanese government's aggressive science technology and industry policies.

These policies, especially Japanese industry sector policies, have in fact violated many of the prescriptions for a nation's economic growth and industrial development contained in classical economic and international trade theories. The growth of the Japanese economy and the very rapid increase in Japanese exports in spite of these "violations" may be explained by two interdependent factors. The first of these, is the fact that Japanese policies did not abuse the prescriptions for orderly markets in which the forces of supply and demand dominate. Rather, Japanese governments policies were sufficiently bold and comprehensive to override all of the orderly free market mechanisms. Thus, the Japanese government not only "controlled" the level of production but also "controlled" the level of prices. The adherence by the Japanese private sector to these "controls" which took the form of "administrative guidance" must be attributed to the cohesiveness of the Japanese people.

The second factor which made it possible for the Japanese government policies to work was the fact that the principal trading partners with Japan, the U.S. and the EC nations, did very

little to retaliate against these policies, or at least did very little until the mid-1980's. The reasons for this unwillingness to react to Japanese policies, (some of which were obvious transgressions of established rules and order which govern international trade) were of course political.

The same political considerations on the part of the U.S., EC member countries and other Western democracies allowed Japan to concentrate on economic development and growth, without requiring Japan to expand resources for their national defence.

While the Japanese government deliberately broke the rules of economic theory in its growth and international trade activities, the same government either deliberately or by chance followed the guiding economic principles in industrial development for a nation which is a "latecomer" or behind other nations in industrial development. As outlined by the economic historian A. Gerschenkron (1947) the best chance for a latecomer nation to catch up with the others in industrial development is to close the gap as quickly as possible with government policies similar to those executed by the Japanese.

Not all Japanese policies and MITI projects have met with outstanding success however, indeed among MITI's projects which were not successful were the attempted development of a native Japanese aluminum smelting industry on which the Japanese

government spent \$2.5 billion, and which in 1988 consisted of two marginal smelters, operating at a considerable loss. There are other examples of policy errors, including the now abandoned project to design and construct a nuclear-powered blast furnace for steel making which MITI supported in the 1973 to 1980 period at a cost of \$110 million, or MITI's project from 1980 to 1986 to design a process of petrochemical production from carbon monoxide which cost the Japanese government \$84 million and was abandoned in 1987.

For the most part, however, the Japanese government and MITI's selected policies and projects have worked very well. MITI's emphasis on the need to obtain technologies developed by others was very successful. Many, if not most, of the advanced technologies used in Japan have been developed elsewhere and obtained by the Japanese through licensing and other means. Indeed the Japanese "imports" of advanced technology licenses have increased continuously over time. James Abegglen and George Stalk in their book "Kaisha-the Japanese Corporation" (1988) estimate that between 1950 and 1980, in 30,000 separate agreements, Japan spent \$10 billion to acquire technology from the U.S. and the EC nations. The Japanese demand for foreign technologies has not declined since 1983.

However the policies of the Japanese government over the last several decades have stressed basic research as well as applied

research and development activities. There is some evidence that this emphasis on the need for basic scientific research is increasing basic scientific activity in Japan. For example, Japan's share of the world's scientific literature increased from 5.1 percent to 7.6 percent over the 1973 to 1984 period, and U.S. patents granted to Japanese inventors increased from 4 percent in 1970 to 19 percent in 1986. Similarly, the ratio of Japanese payments for foreign technologies to Japanese receipts for technologies purchased by other nations during the 1980 to 1986 period shows a very rapid decline, indicating the increasing stature of Japan's own science and technology achievements.

In the case of the microelectronics sector, Japan has certainly overcome the U.S. and most probably will dominate this advanced technology industry in the future. The fundamental reason for Japan's success up to the present time has not been, however, advancement in microelectronic technology but access to capital to construct microelectronic device manufacturing facilities. John Markoff (1989) in his review of a book by Fred Warshofsky "The Chip War: The Battle of the World Tomorrow" summarizes the critical differences between the U.S. and the Japanese microelectronics industry as follows:

The image that emerges in "The Chip War" is of an industry that is dangling by a thread, in danger of going the way of the television and videocassette recorder industries before it. In his final chapter Mr. Warshofsky, a science writer, captures the bitter frustration of the president of a modest-sized Silicon Valley chip-making equipment company. The businessman

is trying to match the investment of his Japanese competitors, with their easier access to capital and their insulation from greedy Wall Street shareholders who look no farther than the next quarter's profit-and-loss statement.

The future demand for the microelectronic product market will require further expansion of microelectronic product facilities. A 1989 Economist article places Japanese capital commitments for their own expansion at about \$4 billion. The private microelectronics sector in the U.S. cannot match these requirements and it is not likely that the U.S. government, for all its concern about the U.S. microelectronics sector, will attempt to provide the required funds. Even if such an attempt is made, it may be refused by the independent minded U.S. firms. There are more problems ahead for U.S. microelectronic manufacturers. As reported in the Economist:

American semiconductor firms can expect still-more sleepless nights. MITI wants to get Japanese semiconductor makers out of low added-value memory devices and into the lucrative top end of the market -- making advanced microprocessors ("computers on a chip"). Not only are microprocessor devices more valuable, but each one sole requires a handful of other proprietary circuits to support it. Thus the company that gets its microprocessor specified as the "brain" of a particular brand of personal computer or workstation wins orders for many more supporting circuits as well.

Intel and Motorola have dominated the worldwide microprocessor market. To ensure adequate supplies, they have traditionally licensed other manufacturers to act as second sources. But with their latest generation of designs (Intel's 80386 and Motorola's 68030), the two American companies have steadfastly refused to sell second-source licenses, fearing the loss of the technology as much as an erosion in prices.

The inevitable has happened. Japan's top-notch electronics firm, NEC, has gone it alone and produced a full range of similar (but cleverer) microprocessors. The signal to commit

itself whole-heartedly to microprocessor manufacturing came last month when a Californian court ruled that NEC had not infringed Intel's patents when it developed its V-series of "work-a-like" microprocessors that were plug-compatible with the American firm's but worked faster.

With the long-running legal problems out of the way, NEC has moved quickly to announce a new series of 32-bit microprocessors that out-perform anything Intel or Motorola has on offer. NEC's only worry now is not the next generation of American microprocessors but the ingenious tricks being conjured up by Fujitsu, Toshiba and Matsushita. Next year, Japanese semiconductor firms are expected to produce almost as many advanced microprocessors as memory circuits. And America's chipmakers will face another tough fight." (Economist, March 18, 1989).

In the case of the machine tools industry, the Japanese have been able to penetrate the international markets for machine tools, formerly held by the Germans and U.S. because of the Japanese ability (MITI directed) to merge the old vintage "steel" technology of machine tools with microelectronic devices. The German and U.S. machine tool makers, bound by tradition and limited by expertise to the old vintage technologies in machine tools did not and could not master the new and rapidly changing microelectronics component in machine tools. It is not likely that any policy or inducement by German or U.S. governments would have persuaded their machine tool makers to utilize microelectronics in their design, engineering and production of machine tools. The presence of existing and well established, albeit old vintage, machine tool industries in Germany and the U.S. prevented new enterprises from entering this sector of the industry.

In Japan the ever obedient industry establishments followed the guidance of MITI and, supported by Japanese government funding, were able to design and manufacture machines tools and robots technologically far more advanced than the German and U.S. competition. The policies of the Japanese government to provide assistance to Japanese firms in the sales of these Japanese products and in after-the-sale services have resulted in a rapid increase in Japanese machine tool exports.

The advanced ceramics industry sector has received significant assistance from the Japanese government and represents the technological advancement of a major and historical Japanese industry. It is reasonable to assume that the Japanese advanced ceramic industry will become a major factor in the future.

Advanced materials based on polymers are essentially a technological extension of the organic chemicals industry with petrochemicals as the precursor. The Japanese petrochemical industry has not been well developed in the past, principally because of the absence of the raw material -- crude oil -- and therefore it is not surprising that this segment of the advanced material industry cannot be included among Japanese technological advancement.

In the case of composites, the absence of Japanese policies or projects to engage in research and development activities for this

very important technology is surprising. Certainly, the Japanese automotive industry, instrument makers, and anticipated Japanese future emphasis on aerospace, would dictate a serious research effort by the Japanese on composites.

One explanation for this is the virtual absence of technical information on composites. Most of the research, development and engineering activities associated with composites undertaken by the U.S., the principal nation engaged in composite manufacture, are conducted for defence-related applications and therefore not readily available. Certainly, that the Japanese vigorously attempted in 1989 to reach an agreement with the U.S. on the production of the new fighter plane FSX, which utilizes composites to a significant extent, supports the above suggestion.

FOOTNOTES TO CHAPTER 12

- (1) Japan had adopted an active strategy for technology transfer and modernization from the time of the Meiji Restoration in 1968. However, the techniques and policy instruments have varied according to both domestic and international circumstances.
- (2) MITI employs an elaborate system of support of industrial R&D that includes the operation of its own laboratories and the award of contracts and loans to industry. A distinguishing feature of MITI's R&D function is its employment of a National Project system to concentrate on R&D areas considered to be of special importance to the nation's future. The MITI institutes participate in these projects although they are carried out primarily by industry. Industry is expected to share in the cost as a condition of participation. MITI determines which industrial organizations are to be permitted to join a given project. Typically only the largest corporations with the best research capabilities are invited. In the past, these projects were heavily biased toward applied research or experimental development, but now are moving more toward the basic end of the research spectrum.

- (3) Government funding is usually predicated on the formation of an association of participating companies. For example, the Civil Transport Development Corporation was set up to represent three Japanese manufacturers in the Boeing 767 joint venture with Boeing and Aeritalia. The Japanese Corporation is responsible for 15 percent of the project, and the three participating Japanese companies have divided workshares. The Corporation acts as the conduit for government money and as the agency responsible for coordinating the project. Although a small group within the Corporation is currently studying the next generation aircraft project, a new association may be set up as the coordinating body once the project gets underway. Similarly, the Japanese Aeroengine Corporation represents three Japanese manufacturers in the joint engine development project with Rolls Royce.
- (4) The special corporation established in 1981 by the Science and Technology Agency, called the Research Development Corporation of Japan, inaugurated a new research system in 1981 for the purpose of fostering innovation in advanced technologies. Termed "ERATO" (Exploratory Research for Advanced Technology) the system is centred around key individuals who serve as project directors. Each project team is made up of

scientists from the academic, government, and private sectors, as well as from other countries. They engage in research on open-ended projects for periods of up to five years. The fields of research are outside the traditional academic disciplines and are designed to generate break-throughs in various interdisciplinary areas. Seven projects were underway in 1987 with a total annual budget of 2,210 million yen. Another special corporation, called the Institute of Physical and Chemical Research (Rikagaku Kenkyusho or "Riken" in Japanese) is also under the aegis of the STA; and is one of the oldest research organizations in Japan.

CHAPTER 13:
ANALYSES AND CONCLUSIONS

13.1 INTRODUCTION

The three advanced technology sectors discussed in this thesis, microelectronics, machine tools and advanced materials comprise a very important advanced technology segment of any nation's industrial apex.

Microelectronic products are cardinal to the manufacture of all computers, all communications systems, most home entertainment products, a very large proportion of instruments and control devices of all kinds. Microelectronic technology and the industry itself emerged only in the early 1960s. Technology advancement in microelectronics has no equal in the annals of technological growth (NAS, 1983). The machine tool industry was established in the mid-1850's, and remains a major manufacturing sector in any industrial society (NAE, 1982). Machine tool sectors manufacture the machinery that produces all other machinery, including other machine tools. During the last twenty years, the technology embodied in machine tools was radically advanced by combining the metal cutting and working components of machine tools with the controls based on microelectronics (NAS, 1983). Advanced materials represent a very recent technological innovation reported about a decade ago. The potential future economic impact of advanced materials on all industrial sectors is exceptional because advanced materials may

replace most of the traditional raw materials used in the production of industrial and consumer products (NAE, 1988).

13.2 SUMMARY OF GOVERNMENT POLICIES

Table 13.1 presents the past trends and immediate future prospects for worldwide sales volumes of these three advanced technology products.

The differences between France and Japan lie in the manner of the administration of these policies. Japanese policies were administered after a consensus of these policies was reached among the sectors of Japanese society. The French government essentially dictated its policies without an attempt to reach a consensus.

Both nations selected "target" industry sectors destined for rapid growth; both France and Japan enacted policies that established very large scale, government supported programmes to advance the selected industry sectors; both countries provided significant funding to the selected sectors; and both countries attempted to protect the selected sectors against international competition. The Japanese government succeeded in its policies, whereas the French did not. The reason for these different policy outcomes lies in a difference in how the policies were administered and in the geographic, political, economic and social environment of a country within which all government policies must operate. The Japanese

Table 13.1

**Microelectronic Products; Machine Tools and
Advanced Materials Past Trends and Mean Term
Projections of Worldwide Production, 1960-1995
(in billions of current dollars)**

	<u>1970</u>	<u>1980</u>	<u>1988</u>	<u>1990</u>
Microelectronic Products	\$3.1	\$12.6	\$47.4	\$132.0
Machine Tools	\$8.3	\$13.6	\$38.4	\$ 61.0
Advanced Materials	0	\$ 3.0	\$19.0	\$ 88.0

Source: SHC, 1988

were able to utilize Japan's social and political characteristics as a receptive environmental for their policies, with a deliberate effort to achieve consensus among the population. The French, faced with a dual economy and preoccupied with government-controlled enterprises, issued regulations not accepted by large sectors of the French population, instead of attempting to achieve consensus.

The evidence suggests that there is no single optimum model for government policies that intervene in the markets and result in economic growth, the rapid technological and economic development of an industry sector or the enlargement of domestic and international market shares. On the contrary, the dominant requirement would seem to be a diversity of government policies, custom tailored to the geographic, political, economic and social characteristics of a nation and to specific industry sectors.

It should also be emphasized that there may be a need to change government policies over time to respond to changes in a nation's geographic, political, economic and social characteristics.

For example, in the case of Japan, MITI's policies that were successful in the 1960s and 1970s may be ineffective in the 1980s because Japan's industrial firms have ample resources for operations on their own and therefore do not require MITI's assistance. Likewise, some of the government's policies prescribed by the "new" economic theory may not be feasible for Western European nations after 1992 because of the Common Market's agreements and provisions.

The empirical evidence on international trade presented in Chapter 3 combined with the analyses of governments' policies in the five countries (Chapters 8, 9, 10, 11 and 12), clearly identifies the major role government policies can play in the growth of industry sectors in a nation as well as in that nation's ability to expand its international trade. These analyses indicate that government interaction in the free markets may, for a specific nation foster industrial development and increase exports, as in the case of Japan, or may yield little, if any, improvements in a country's economic growth as in the case of France. An analysis of the various factors that may account for this discrepancy suggests that it may be explained by examining the process by which government policies are enacted. This process is determined by the unique characteristics of the various components that make up the government policy-making process (Allen, 1978; Arnold, 1986; Balcerowicz, 1980). The unique characteristics of the various components, in turn, are determined by the socio-economic characteristics of a nation's population, its geographic attributes, history, economy and industrial base. These components shape the political system of a nation which in turn produces a government which enacts government policies. Government policies, of course, have an impact on the various components that make-up the entire policy-making process.

The role played by the characteristics of the various government policies for a nation may best be illustrated by a summary description of the five nations.

13.2.1 France

France had a distinguished history of industrial and technological advancement in the 19th century supported by a growing population in Metropolitan France as well as French colonies in Africa and Southeast Asia. Since World War II however, France's industrial accomplishments have been marginal. Part of this can be explained by the loss of the French colonies and the political upheavals that accompanied this loss. However, a major reason for the lacklustre French technological and industrial performance has been the effect of the French government's policies. As presented in Chapter 8, the French government throughout the post-World War II period attempted to create advanced industry sectors that matched or even surpassed those of the U.S. (Chararon, 1989; Fabian, 1984; Gilpin, 1968). These sectors were to represent French "national champions" and were to be created by the use of a very comprehensive set of French government policies, the so-called "grands programmes," such as the Plan Calcul (Gilpin, 1968). These policies were applied to such advanced industry sectors as microelectronics, computers, steel, telecommunications, aerospace and motor vehicles.

None of the French government plans was successful, partly because French government planners emphasized the supply of advanced technology products rather than the market demand (SHC, 1988). French plans failed also because the government failed, or did not even try, to explain and achieve acceptance for the policies from all segments of French community (SHC, 1988). Competition from the U.S. and Japan also helped to negate French government policies.

One of the components of the French government intervention in the free market mechanism was its ownership or control of the French industrial base. As of 1989, about 50 percent of French industry is government owned or controlled. This in turn has resulted in a distinctly dual nature of the French economy. On the one hand there are French industrial establishments that are controlled by the government and equipped with state-of-the-art technology in production facilities, on the other there are the privately owned industrial firms that are relatively small and employ old vintage manufacturing methods and production machinery (Gruber and Vernon, 1970; Mistral, 1980). The demand for advanced industrial goods generated by these privately owned industrial enterprises is modest and not sufficient to establish domestic demand for the products of the French government-owned sectors (Sheperd, et al., 1983). International markets for French advanced technology products, as noted in Chapter 8, are limited because of the French government's policies of designing and manufacturing industrial goods that are

uniquely French and therefore difficult to match with industrial products manufactured by other nations. French export policies also did not match the inducements provided for exports by the Japanese, German and to a lesser extent U.S. firms (Shimo, 1982). The French political system continues to be dominated by French government "functionnaires" and continues to emphasize rigid policies dictated by the French government offices, rather than seeking consensus and considering the views of the French (and foreign) markets (Luscovitch, 1985).

Government policy making in France has always emphasized the need to develop and sustain a uniquely French capability in science, technology and industry. French government industry sector policies continue to be directed from the top down and continue to exclude consideration of other nations, and, to a certain extent, international agreements (Saunders, 1978; SHC 1988). For example, while the French government has decreased its defence-related spending, there exist in 1989, French government directives focused on providing financial assistance to the French defence firm Thomson-CSF to become a major contributor to the force de frappe (Rowen, 1989). Advanced technology industries in France remain relatively ineffective in world markets. The output and sales of advanced technology goods, produced by multinational firms located in France is increasing at a moderate rate. Japanese exports of advanced technology products to France increased significantly in 1988 (SHC, 1988).

13.2.2 Germany

Following World War II, the German industrial base, heavily damaged during the war, was rebuilt with significant assistance from the Marshall Plan (Kocka, 1980). By the year 1958, German industrial capacity in most sectors of the economy exceeded that of 1941. Most of the rebuilt industrial facilities were equipped with state of the art technology and operated by an exceptionally well-trained labour force. The homogeneity of the German labour force and the cooperative relations between German labour unions and management resulted in high industrial productivity (Massow, 1983; Peacock, 1980). The German federal government, as a result of the experience during the Nazi era, deliberately abstained from central policy making in all areas including science, technology and industrial developments. German industry, therefore, has operated essentially in free markets.

Some premises of the "new" economic theory have been observed by Germany's private sector and a number of initiatives in concert with some of the elements of the new economic theory have been undertaken by German firms.

For example, in order to achieve economies of scale, avoid duplication in research, development and distribution, and to increase funding for research, development, engineering, and capital expenditures, several German microelectronic firms have concluded

cooperative, joint production and similar arrangements, with other German enterprises as well as with the firms of other nations. These include Siemens A.G.'s arrangements with the Japanese Toshiba Corporation; Siemens A.G.'s joint venture with N.V. Philips from the Netherlands and extensive cooperation joint distribution arrangements by Telefunken A.G. and several U.S. microelectronic firms (Rowen, 1989).

As analyzed in Chapters 6 and 9 the German machine tool industry has experienced a relatively severe decline as a result of Japanese competition. The principal underlying reason for the Japanese success was their ability to advance machine tool technology by merging microelectronics-(microprocessors) with metal cutting operations. The German machine tool manufacturers have recognized this Japanese achievement and have during the last several years attempted to match Japanese technology. They have been largely successful in their endeavour, but have still lost a significant segment of their domestic and international markets for machine tools to Japanese firms.

In advanced materials, German industry has had limited interest in the past, except for advanced ceramics used in internal combustion engines. Since 1988, German industry has recognized the potential value of advanced materials in numerous applications and has initiated research and development activities in this area. The merger, in the autumn of 1989, of the largest German industrial

firm, Daimler-Benz with Messerschmitt-Balkow-Blohn (MBB) is of particular significance to German advanced material development, because both firms have been the leading German enterprises in advanced materials research, development and engineering.

In summary, German advanced technology firms have undertaken a number of actions that correspond to some of the prescriptions for industrial growth advocated by the new economic theory. In concert with the past German adherence to the free market, these activities have been carried out by the German private sector in the context of free market activities and not by the German government's policies.

13.2.3 The United Kingdom

The post World War II era left industry in the U.K. without the assured markets of the colonies for industrial and consumer products. The home market was not of sufficient magnitude to support the large industrial base in the U.K. (Palmer, 1987; Prais, 1976). Unlike the cases of Japan and Germany where industrial facilities had to be rebuilt, and were rebuilt with advanced technology machinery and equipment, a large segment of the U.K. industrial plants after World War II remained equipped with old production facilities.

The declining demand for U.K. goods resulted in a reduced demand for employment. The Labour government attempted to maintain

employment levels through a series of policies that included nationalization of industry sectors and firms (Strodt, 1981). As the result, entrepreneurship in U.K. industry decline with a corresponding decline in the utilization of advanced technologies in industrial production. Prime Minister Thatcher's three successive governments since 1979 have radically changed economic policies in the U.K. with the privatization of industry (since 1979 a total of 54 state-owned companies have been sold to the private sector) and aggressive science and technology policies (SHC, 1988). U.K. industry has attempted to become more competitive by creating, via takeovers, industrial enterprises with sufficiently large manufacturing facilities to gain advantages from economies of scale in production. For example, in the autumn of 1989, GEC in cooperation with Siemens took over another U.K. electronics firm, Plessey, in order to be able to compete against such American firms as Boeing, Lockheed and MacDonald Douglas. However, U.K. industry is facing formidable competition in the domestic as well as international markets from Japan, the U.S., Germany and from increasing numbers of multinational firms.

In the last decade, several industry sectors in the U.K. have experienced radical changes, as compared to what occurred under previous U.K. governments. Defence-related industrial activities increased in importance to the point where approximately 60 percent of the U.K.'s microelectronic production was defence-related in spite of the government's attempts to reduce this trend (Waterson

and Lopez, 1983). There have however been increases in industrial output and profits for some industry sectors and a modest increase in U.K. exports has occurred. Some of these changes may be attributed to the conservative political philosophy of the Thatcher government. The privatization of important sectors of the economy such as communications, steel and motor vehicle production is part of this conservative policy trend. The relatively recent trend of mergers, takeovers, and acquisitions on the part of U.K. firms may be partly attributed to the prevailing philosophy of the British government. The resulting aggregation of U.K. enterprises has improved the competitiveness of U.K. firms vis-a-vis foreign entities. In the area of science and technology, the government has enacted policies to encourage the application of commercialization, fully recognizing that applied research in the U.K. has not kept pace with other nations (Bide, 1986).

In spite of these changes in industry and the government's attempts to convert U.K. accomplishments in science into marketable products, the U.K.'s presence in world markets for most products and certainly for advanced technology products has been reduced. In microelectronics the performance of native U.K. firms has been modest in terms of domestic and international sales as well as technological advancement. An increasing proportion of microelectronic products used in the U.K. or exported are manufactured by U.S. and Japanese facilities located in the U.K. The one attempt by the government to establish a major native microelectronic device

manufacturer (INMOS) resulted in only partial and temporary success. Conversely, foreign microelectronic firms in the U.K. are expanding their production, as well as domestic and international sales.

Recent mergers and takeovers in the U.K. microelectronics sector (such as that of the General Electric Company's takeover of Plessey) have created microelectronic enterprises of sufficient size to undertake the required research and development effort to advance the technology of the U.K.'s microelectronics industry.

The U.K.'s machine tool sector has been plagued historically by the existence of many small toolmaking enterprises. For at least the last thirty years, various governments have pursued a continuous policy of arranging or forcing mergers between some of the smaller toolmakers (Gibbons and Gummett, 1979; Hart and Morgan, 1977). To a considerable extent these policies have been successful and the remaining U.K. machine-tool firms are fewer in number and larger in size. Nevertheless, most of these remaining firms do not have the required resources to compete with the German or Japanese toolmakers in the manufacture of advanced technology machine tools.

Research, development and engineering efforts in advanced materials have received marginal attention in the U.K. industrial community with only limited activity undertaken by science establishments in the U.K. However, the well developed chemical industry sector in the U.K., combined with U.K. scientific

establishments engaged in materials science, surface chemistry, and solid state physics, offer promise for the advanced materials sector in the U.K.

13.2.4 The United States

In the immediate post-World War II years, the U.S. was the principal industrial nation that dominated all others. The very large size of the domestic market in the U.S., combined with the relative scarcity of consumer goods during the war years allowed U.S. industry to concentrate on domestic markets with very limited attempts to export (Chandler, 1980). Government policies with regard to market functions have traditionally been limited to health and welfare considerations and have not addressed other issues. However, the emergence of the Communist threat in the late 1940's forced the U.S. government to enact some limited policies to enhance defence-related research, development, engineering and industrial production activities (Jorgenson, et al., 1988; Kennedy, 1987).

Government interventions in market functions, however, in the two decades after World War II remained essentially non-existent. In the late 1960s, U.S. firms began to compete in the international markets mostly using U.S. based multinational corporations as the vehicle (Lunn, 1983; Modigliano, 1983). The growth of Japanese exports which competed both in U.S. domestic markets and with the U.S. based multinational firms in international markets, forced U.S.

industry to consider government policies that would enhance the U.S.'s capability to compete (NAS, 1988). Due to long-standing public opinion against most federal government policies (other than defence and health and welfare related), market functions have however, remained relatively free from government intervention. This is in spite of the very significant decline of U.S. industry, in particular in the advanced technology sectors.

Recent trends in the terms of trade in advanced technology products show a steep downward movement. Further, many observers suggest that in the areas of science and technology there has been some decline in the status of the U.S. (Abernathy and Rosenbloom, 1981; Adams, et al. 1983).

There is also some concern that the leadership and management of science and technology activities in the U.S. was not satisfactory during the two terms of President Reagan (Hanger, et al., 1986). The available statistics on international trade identifies the U.S. as a nation with a rapidly declining performance in exports of advanced technology products during the two terms of Reagan's Administration.

President Bush's promise to the American public during the 1988 election that his Administration would install new leadership in the OSTP with broad policy powers has been fulfilled. The new Director of the OSTP, Dr. Allan Bromley, is a respected scientist with

considerable federal government experience. His previous assignment was that of Director of the Wright Nuclear Structure Laboratory at Yale University and he is well liked and respected by the scientific community in the U.S.

Dr. Bromley's first task was to appoint a comprehensive President's Council of Advisers on Science and Technology (PCAST) consisting of twenty well known scientists representing academia, research laboratories and industry in the U.S. Dr. Bromley asked for and received an annual budget for the OSTP of \$3 million as compared to \$1.5 million during the Reagan years. Dr. Bromley's request for government sponsored annual research and development expenditure is over \$20 billion as compared to \$10.4 billion in 1987.

Even more important, Dr. Bromley is very much aware of the importance of science and technology policy in the development of advanced technology sectors and of the critical role that science and technology plays in foreign trade. In order to introduce coherent national science and technology policies in the development of U.S. advanced technology sectors and in order to reverse the large negative trade balance in advanced technology products, Dr. Bromley has initiated a number of OSTP policies intended to provide a comprehensive review of the present status in these areas and to organize a cohesive and unified research and development programme for the U.S. science establishment. All indications point to an

active federal government science and technology policy supported by the Bush Administration.

This is not the case with the U.S. industrial policy directed by the U.S. Department of Commerce Secretary Robert Mosbacher. In spite of the fact that Mr. Mosbacher is a close personal friend of President Bush, his attempts to provide policy guidance to U.S. industry were turned down by the U.S. Budget Director Richard G. Darman and the Economic Council Chairman Michael Beskin. According to Rowen (1989), Mr. Mosbacher was "... read the riot act," told that "... it's not the government's function to pick industry sectors winners and losers" and that there is no need to "... adjust standard Republican free-market principles to political reality." Mr. Mosbacher's reply to the opposition was that he was being sniped at by "... anonymous midgets at the seat of the mighty at the White House commenting on matters to which they were not a party" (Rowen, 1989). It appears, however, that Mr. Mosbacher's attempts to develop federal government policies for U.S. advanced technology industry sectors under the heading of "industry-led strategy," as a substitute for the Republican Party's rejected "industrial policy" concept, has failed.

It is of some interest to note that Mr. Mosbacher's specific policies proposed under his "industry-led strategy" were relatively mild as compared to the industry policies recommended by the new economic theory. They contained a modification of the U.S.

antitrust laws that would allow joint research and development expenditure, research and development tax credits, government financial assistance to selected advanced technology sectors for capital expenditures and some control over foreign (mostly Japanese) investment in key U.S. advanced technology sectors.

All of these policies are in force in Japan and France, and some (such as research and development tax credits and joint research and development activities) are practised in Germany. The U.S. government, however, continues to adhere to the classical economic prescription of non-government intervention of any kind.

The status of advanced technology industry sectors in the U.S. has deteriorated in 1989 in that exports of advanced technology products have declined (although at a lower annual rate than during the previous six years). More important, Japanese firms have continued to establish their own production facilities in the U.S.

The microelectronic industry in the U.S. has reacted to this by establishing research and development consortia and forming joint ventures. Citing the critical need for domestic production of computer memory chips, seven U.S. semiconductor and computer manufacturers in 1989 banded together to finance the establishment of U.S. Memories Inc., only to dissolve this joint venture in 1990 because of funding shortages.

It is questionable, however, whether U.S. Memories or any other privately financed enterprise could have succeeded without federal government assistance. For example, Institute of Electric and Electronic Engineers (IEEE) officials argue that it is time for the U.S. government to act by providing an "hospitable antitrust environment" and equalizing capital costs and risks for U.S. companies competing in global markets (Rowen, 1989).

U.S. microelectronic firms are also challenging continuing Japanese growth in the U.S. by forming joint production ventures. These include a joint venture by IBM and Texas Instruments to construct microelectronic manufacturing facilities, a joint venture between the Digital Equipment Corporation and the Intel Corporation to produce logic devices and a joint venture between the LSI Logic Corporation and the National Semiconductor Corporation to manufacture microelectronic arrays (SHC, 1988).

The driving force behind these activities is Japanese competition of two types; competition in world markets and competition by way of establishing production facilities in the U.S.

With regard to the former, U.S. microelectronic firms have chosen to meet the Japanese head-on with lower cost U.S. microelectronic products and marketing practices. (There exists, however, a significant divergence of opinion between the U.S. industry and U.S. government as to whether or not the U.S. government should abandon

their free-trade philosophy and directly assist U.S. firms in foreign markets.)

With regard to the Japanese competition in the U.S., via establishing production facilities in the U.S., there is no unified opinion among U.S. industry or U.S. government officials as to the required response. There exist among some U.S. government officials and industry leaders so-called "chrysanthemum club" members who consider Japan as partners in the struggle against the Soviet Union. The "chrysanthemum club" members welcome Japanese production facilities in the U.S. and seek general accommodation with the Japanese in trade disputes (Fallows, 1989). The other group of U.S. officials, industry executives and members of academia, referred to as "revisionists" consider Japan as an "enemy," a nation that operates not in concert with established international relations (van Walferen, 1989; Prestowitz, 1988; Fallows, 1989).

The opinions that divide these two groups reach beyond immediate trade issues and address the fundamental question of whether or not U.S. microelectronic firms (as well as U.S. enterprises in other sectors of economy) can and should cooperate with Japan.

The traditional U.S. machine tool firms remain in a poor financial position and face increasing competition from Japanese and German tool-makers. In the past decade the number of traditional

U.S. machine-tool firms has shrunk from some 90 to less than 30 in 1989 (SHC, 1988).

In the field of advanced materials the U.S., as of autumn 1989, has a virtual world wide monopoly in technology and manufacture of advanced material products, except for advanced ceramics where the Japanese firms dominate.

The advanced material industry in the U.S. is, however, in a unique position in several respects. To begin with, it represents an advanced technology sector that has only in the last few years emerged from the research, development and engineering phase and entered the phase of (limited) production. A very large proportion of the advanced materials that are manufactured are purchased by the U.S. federal government for defence-related applications. Commercial or private sector uses of advanced materials are limited, although available projections suggest an annual market for commercial application of over \$88 million by 1995. The U.S. DOD has funded most of the research, development and related activities for advanced materials in the past. However, improved relations with the Soviet Union are expected to reduce DOD budgets which in turn may significantly reduce advanced material research and development activities (NRC, 1984; Rowen, 1989).

In spite of the significant market potential of advanced materials, the U.S. government (except for the U.S. DOD) has

expressed no interest of funding additional research and development.

Japan, which already has an extensive research and development programme in advanced ceramics, has for some time been attempting to obtain advanced materials technology from the U.S. Because of the defence-related uses of this technology, Japan was not successful in its effort until 1989 when the U.S. government agreed to share some of the advanced materials technology with Japan in a joint programme to design and build a new generation of fighter aircraft, the FSX (SHC, 1988; Rowen, 1989).

The Japanese government has assured the U.S. that the use of the advanced materials technology by Japanese firms will be "controlled and restricted," although these Japanese assurances are somewhat vague (Prestowitz, 1988).

13.2.5 Japan

The geography of Japan makes it very poor with regard to national resources and Japan has been forced to rely almost exclusively on raw material imports (Shimo, 1982). This in turn has required Japan to depend on exports to pay for the required imports. The Japanese industrial base, essentially destroyed during World War II, was reconstructed and equipped with advanced machinery and equipment during the 1945 to 1955 period.

The Japanese political system, with the Emperor as a titular head has been very stable with one party, the Liberal Democrats, in control since the end of World War II. The homogeneity of the population has maintained a common national goal and ever since the Meiji restoration period, that began in 1861, the population has followed the policies set forth by the Japanese government. The government for its part has successfully practised consensus building policies (Johnson, 1982). Japanese policies to foster advanced technology industries in Japan have been accepted by the population with a sense of obligation and duty (VanWalferen, 1989).

As a result of these factors and the government's policies, Japanese economic growth and superior performance in the international markets has been unprecedented in the post-World War II period. Chapter 3 presents statistical information to support this statement and Chapter 12 presents information on the past and present Japanese science and technology achievements.

As stated by Narin and Frame (1989):

"When future generations of historians look back on the second half of the 20th century, one of the most significant historical developments they are likely to identify will be the phenomenal growth of Japanese economic strength. In the relatively short period of four decades, Japan has grown from modest economic means to become the second most powerful economic entity in the world. Historians will note that this growth was based not on the acquisition of territory or natural resources, but on the wise acquisition and employment of technology.

However there are notable changes in Japan in that MITI, the Japanese agency that has been the principal author of the Japanese government's science, technology and industry policies, has lost much of its power to author, enact and enforce such policies (Sanger, 1989). For the most part, this has been the direct result of Japan's economic growth. Japanese industry no longer requires government policies that would enhance its prospects nor do Japanese firms need MITI's financial assistance. For example, Hitachi Ltd. alone spent about \$2.2 billion on research and development in 1988, or about 50 percent more than the entire MITI budget.

This does not mean however that the Japanese have or will become less competitive. As stated by Sanger (1989):

"MITI's loosening grip will not make Japan a less formidable competitor. In the long run it may even pose bigger problems for the United States. The absence of central government control has already triggered spending wars here -- on R&D, more production capacity and more automation -- that seem bound to put American companies at a greater disadvantage."

Indeed Japanese advanced technology sectors have increased their research and development expenditures as well as the construction of new manufacturing facilities in Japan, the U.S. and in the European nations, and they have done so without prodding by MITI. Recent Japanese marketing activities indicate the strong emphasis being placed by Japanese firms on opening markets for their micro-electronic products in China and the Soviet Union. Whereas, only a few years ago the Japanese were reluctant to sell their micro-electronic products to the Soviet Bloc, the attempts by the U.S. to

increase its trade with Soviet Union will provide Japanese firms with the justification to enter these new markets (Rowen, 1989).

In the machine tool industry Japanese firms have increased their sales in most countries and have significantly replaced German machine tool products in the U.S., in European nations and even in Germany.

In advanced materials technology the Japanese have a distinct advantage in advanced ceramics, but lag in technologies for other types of advanced materials. However, Japanese industrial firms have access to considerable funding from their own operations as well as from the Bank of Japan; sources of funding that cannot be matched by U.S. firms without deliberate U.S. government policies to provide financial assistance.

13.3 ORIGIN AND GEOGRAPHIC DIFFUSION OF ADVANCED TECHNOLOGY

Classical economic theory stipulates that a country with the appropriate specific natural and man-made endowments has comparative advantage over other nations for sectors of the economy that require these specific endowments. Such a country is the obvious origin for such products (Deardorff, 1980).

Analyses undertaken in Chapter 2 suggest that in terms of scientific and technical endowment and activities there are only

marginal variations among the five countries covered in this thesis. There exist among the five nations differences in what economists refer to as "national character," that is, unique characteristics of the natural, institutional and man-made environment (Dunning, 1981). When the contributions of national character are taken into account, classical economic theory may provide a reasonable argument for the geographic origin of the three advanced technologies analyzed in this thesis. In the case of microelectronics, the very large electronics industry populated by large numbers of electrical engineers in the U.S. provided an excellent base for research and development activities in electronics that eventually led in 1961 to the development of transistors and other microelectronic products (Noyce and Hoff, 1981).

The metal working industry in the U.K. in the 1850's and advanced manufacturing technologies of various metal products provided the basis for the British machine tool industry (Kindlesberger, 1964; Pavitt, 1980). The developments in the fabricated metals sectors in Germany that followed early advances in the U.K. provided the basis for the German machine tool industry (Fawcett, 1976; Kennedy, 1982).

The technological advancements in the organic chemical industry, based on crude oil, in the U.S. during the 1940's and 1950's, established the U.S. as one of the world leaders in the manufacture of polyester resins and other plastics. This tech-

nological base, combined with very large research and development funding by the U.S. DOD for the development of space vehicles and aircraft, resulted in the development of advanced materials based on organic chemicals (Kuhn and Porter, 1980). In Japan, where the ceramic industry has, for several centuries, lead the world in technological achievements, advanced ceramics technology was developed in the mid-1960s (American Ceramic Society Bulletin, 1982).

Classical economic theory, however, not only postulates conditions for the most likely national origins of new (advanced) technology, it also stipulates that economic forces of comparative advantage will ensure that such a country will continue to remain a major world supplier of new (advanced) technology products (Landau, 1988). Classical economic theory stipulates further that any and all intervention by a government on behalf of a nation's industry sectors is futile. Government intervention in free markets (both domestic and international) will, ultimately, lead to a decline in a nation's domestic production as well as to a decline in exports (Lancaster, 1957).

The empirical evidence presented in Chapter 3 contradicts these stipulations. Japan is a prime example of this. As discussed in Chapter 12, the Japanese government's policies that have intervened in domestic and international markets on behalf of Japanese industry

sectors are extensive and have been systematically enacted by Japanese governments throughout the post-World War II period.

Freeman (1989) summarizes this as follows:

"In the immediate post-war period, after an intense debate, Japan specifically rejected a long-term development strategy based on the traditional theory of comparative advantage. This was apparently at that time being advocated by economists in the Bank of Japan and elsewhere who subscribed to the free-trade doctrine of the classical school.

In place of traditional economic theory, the Japanese government relied on policies that emphasized technological growth in selected industries that promised long term growth and markets.

Freeman (1987) explains the government's role in this as follows:

"From that time onwards MITI saw as one of its key functions the promotion of the most advanced technologies with the widest world market potential in the long term. In this respect MITI differed from almost all other analogous ministries in Western Europe or North America, which mostly did not see themselves as responsible for long-term technology policies until much later (that is, in the 1970s or 1980s) and were guided by very different conceptions of comparative advantage.

As early as 1952 the Enterprises Rationalisation Promotion Law provided direct government subsidies for 'the experimental installation and trial operation of new machines and equipment, plus rapid amortisation and exemption from local taxes of all investments in research and development; second, it authorised certain industries (to be designated by the cabinet) to depreciate the costs of installing modern equipment by 50 per cent during the first year; and third, it committed the central and local governments to building posts, highways, railroads, electric power grids, gas mains and industrial parks at public expense and make them available to approved industries'."

During this period, the Japanese economy has experienced unprecedented growth, and Japanese products have replaced those of the U.S., Germany and other industrial nations in world markets (Mansfield, 1988). In the case of microelectronic devices, U.S. microelectronic products monopolized world markets from 1961 to the early 1970s. In 1970, the total worldwide output of microelectronic products was estimated at \$3.1 billion. Approximately 87 percent were manufactured in the U.S. Japan's share of microelectronic products was less than 7 percent. By 1978, Japan's share of world microelectronic products had increased to 27 percent. The U.S. in 1978 had 39 percent of the world market, and the European nations, 26 percent. The remaining 8 percent of the world's microelectronic devices were manufactured by the NICs (Pugel, 1982).

In 1988, the total worldwide production of microelectronic products was estimated at \$47.4 billion. Japan's share of this production was 37 percent or \$17.3 billion; the U.S.', 31 percent, or \$14.9 billion and Europe's, 17 percent, or \$8.1 billion. The remaining 15 percent or \$6 billion of microelectronic products were manufactured in South Korea, Singapore, Taiwan, Brazil and other NICs (SHC, 1988). Japan was able to overcome the formidable lead of the U.S. in the manufacture of microelectronic products in less than twenty years. Furthermore, Europe's share of microelectronic device manufacture decreased from 26 percent in 1978 to 17 percent in 1988 due to Japanese microelectronic export penetration of the French, German and U.K. domestic markets (SHC, 1988). As discussed in

Chapters 8, 9 and 10 these three European nations have only a marginal impact on the world's microelectronic product markets in 1989.

Japanese firms have been able to achieve similar successes in the machine tool sector. In 1970, the total worldwide output of machine tools was valued at \$8.3 billion. Germany was the largest manufacturer with an output estimated at \$1.5 billion, followed by the U.S. with an output of \$1.2 billion, Japan with an output of \$0.8 billion and by the U.K. and France with machine tool outputs valued at about \$0.4 billion each. By 1988, the total worldwide machine tool output was estimated at \$38.4 billion, and Japan had become the largest manufacturer of machine tools with total sales of about \$7.0 billion, representing 16.7 percent of total world production. Germany in 1988 was the second largest manufacturer of machine tools with output valued at about \$6.5 billion, representing 13.5 percent of total world output, a decline from 17.4 percent in 1977. The U.S.' machine tool output has declined significantly during the last decade. In 1977, the U.S. produced machine tools valued at about \$5 billion, and was the largest machine tool manufacturer in the world with a 16.1 percent share of world production. In 1988 the value of machine tool manufacture in the U.S. was estimated at \$2.7 billion, representing 6.8 percent of the total world-wide output of machine tools. In the case of France and the U.K., the value of machine tool manufacture in each of these two

nations has remained relatively stable during the last two decades, with annual values of approximately \$0.8 billion each.

As discussed in the subsequent sections, the growth of the Japanese machine tool industry may be attributed to specific Japanese industry sector policies or "guidance" by the Japanese Ministry of International Trade and Industry (MITI) designed for specific (or "targeted"), Japanese industry sectors. It is important to note here that these Japanese policies have been successful even when directed against a nation such as Germany which experienced significant increases in the sector of industry i.e., machine tools, against which the Japanese products competed.

Advanced materials represent technological developments that are less than a decade old. Most of the research and development effort and certainly all of the production activities of advanced materials (except for advanced ceramics) have taken place in the U.S. A very large proportion of the market demand for the \$19 billion sales of advanced materials in 1988 has been from the U.S. DOD for defence-related goods.

As discussed in Chapters 8-12, interest in advanced materials in other nations, except Japan, has been very limited. Conversely, Japan has exhibited considerable interest in obtaining U.S. advanced materials technology but has been able to do so only to a limited extent because much of this technology has been restricted due to

U.S. defence considerations (National Materials Advisory Board, 1985). The empirical evidence suggests that the origins of the three advanced technologies analysed in this thesis are very much in concert with classical economic theory. Conversely, the diffusion of the advanced technology industries from the "originator" nation to other countries and the rapid growth of these advanced technology industries in the other countries contradicts the basic premise of classical economics and corresponds to the new economic theory (Krugman, 1979; Krugman, 1981).

The empirical evidence that contradicts classical economic theory has, of course, been observed and noted. As a result of this empirical evidence, conclusions have been reached by economists that appropriate government policies focused on specific industry sectors and technologies may overcome another nation's comparative advantage in both domestic as well as international markets. A "new" economic theory based to a significant extent on the appropriate public policies that require government intervention in free markets has been suggested (Krugman, 1983; Spencer and Brandor, 1983). The following section summarizes the salient features of this "new" economic theory.

13.4 THE "NEW" ECONOMIC THEORY

It should be stated at the outset that the new economic theory is not represented by a single all-inclusive formulation. Rather, it comprises a number of studies that are consistent in assumptions

and conclusions but address several components of a nation's economic growth and development, with a particular focus on government policies directed at increasing exports by the nation as a means of improving economic welfare in the country (Krugman, 1984). The principal elements of the new economic theory may be summarized as follows:

a) A nation selects specific industry sectors and corresponding products for development and growth (Krugman, 1983).

b) Products of the selected industry sectors are developed to embody the most advanced technologies. This objective is accomplished either by acquiring technologies from abroad or developing these within a nation via government assisted research and development activities (Bhagwati, 1983).

c) A home market is assured for these products by excluding imports, encouraging domestic consumption (including government purchasers) and controlling prices (Helpmay, 1981).

d) Economies of scale in production are assured for the manufacturers of these products by limiting domestic competition and providing funding for capital expenditures (Hufbauer, 1970; Krugman, 1983).

e) Technology advancements, both embodied in the product(s) and used in manufacturing processes are incorporated by manufacturers as a result of government policies and support (Gruber, Mahter and Vernon, 1967).

f) Long-run, low average production costs are achieved using various government policies (Krugman, 1983).

g) Exports to selected destinations of the low average cost products are initiated, providing to the importer, immediate delivery, long-term financing assistance, ample inventory and prompt engineering assistance services (Johnson, 1957; Aquino, 1983).

h) Exports with government support are extended to world-wide markets (Krugman, 1983).

i) Earnings from export markets are used for the expansion of domestic manufacturing facilities in order to reduce further the average long run costs of manufacture (Casson, 1982).

j) Export markets are extended further with lower export prices resulting from the reduction in manufacturing costs; and

k) Manufacturing facilities are established in other nations in proximity to markets.

It should be emphasized that government policies executed in a form of directives, regulations, recommendations, or in the case of the Japanese government, "guidances," are an integral part of each of the eleven principal elements of the new economic theory. These policies have been used by Japan and to a lesser extent by France, initially in a format that allowed very limited deviation by the firms involved. As the growth of the selected sectors occurred the firms were allowed considerable freedom of action. For example, in the 1960s, the Japanese government (or MITI), using the existing Japanese regulations of foreign exchange control, was able to dictate the specific foreign destination for Japanese exports. During the 1980s, the Japanese government has continued to encourage

exports via a series of financial assistance inducements but has not designated specific nations as trading partners for Japanese firms (Sakikabara, et al., 1982).

Among the five countries included in the analyses, Japan has utilized all of the eleven elements of the new economic theory, and has utilized them very successfully.

The French government has attempted to utilize government policies in concert with some of the elements of new economic theory to direct French industry, but with very limited success. The governments of the U.K. and the U.S. have not used policies as prescribed by the new economic theory or have used such policies to a very limited extent. In the case of Germany, the government has allowed markets to function essentially without any government intervention (Bulmer, 1983; deCarmoy, 1978).

In summary, as shown in Chapter 4, the classical economic theory assumed that the relative abundance of natural resources would provide a basis for the comparative advantage of a nation in specific economic endeavours. The basis for a country's comparative advantage was expanded to include labour force, size of markets, a nation's wealth and related variables. The new economic theory added government policies as one of the determinants of comparative advantage.

A study of government policies in the five nations analyzed in this thesis, suggests that even far-reaching policies by a government may not lead to a nation's comparative superiority in an industry sector unless an appropriate social environment exists in a country. The poor performance by French industry is an example of this. Conversely, appropriate government policies may result in a significant comparative advantage of industry sectors in a country that has few natural resources. Japan, of course, is an example of this. Clearly for government policies to be effective, these must be formulated and enacted in concert with variables that make up the "national character" of a country. The attribute that makes government policies a powerful instrument in achieving comparative advantage for a nation is the ease by which policies may be adjusted or modified in response to the domestic as well as international economic and geopolitical forces. Proper adjustment of government policies, however, requires a well established and well functioning system of government on the one hand and a cohesive and responsive population on the other.

13.5 SUMMARY OF CONCLUSIONS

This thesis has considered two economic theories of international trade -- the classical and the "new" economic theories. Classical economic theory asserts that the achievement of comparative advantage for a certain product will be determined by a combination of factors: a) geographic factors such as location and

natural resources, b) availability of capital; and c) availability of labour.

Underpinning classical economic theory is the assertion that a nation's optimum economic performance will be assured if free markets are permitted to function without interference. Consequently, government intervention on behalf of a nation's industry sectors will will prove detrimental to these industry sectors. Over recent decades, developments in the field of international trade have led economists to question the validity of certain of the prescripts of classical economic theory; as a result, a "new" economic theory has emerged. The new economic theory of international trade maintains that far from being detrimental to a nation's economy, government interaction, in the form of policies, directives and regulations is of vital importance for the advancement of a nation's industry sectors.

The primary objective of this thesis has been to investigate the impact of government policies on the three advanced technology sectors in each of the five countries, and from this, to ascertain which of the two economic theories represents the more valid explanation of current international trade patterns. Based on the statistical and analytical evidence presented throughout this thesis, the following conclusions can be drawn:

a) In the area of advanced technology industry sectors, by far the most important development to have taken place over the last

few decades has been the spectacular performance of the Japanese. Moreover, successive Japanese governments have enacted a continuous and comprehensive stream of policies designed to advance specific industry sectors. The beneficial effects of such policies have been well documented throughout this thesis. As a consequence, one of the central prescriptions of classical economic theory -- that government intervention in the free markets will have a detrimental effect on a nation's economic well being -- must be rejected. In its place, it can be concluded that for the Japanese at least, government intervention has constituted a vital and central component in the phenomenal success of this country in advanced technology sectors over recent decades. This Japanese success stands in marked contrast to the performance of advanced technology sectors in the U.S. and the U.K. Moreover, in both of these countries has been essentially no government intervention in support of advanced technology sectors. This being the case, it is logical to conclude that the central prescription of "new" economic theory -- that government intervention is of cardinal importance -- has been validated by the performance of the Japanese compared with those of the U.S. and the U.K.

b) Despite the above conclusions, it is important to note that government policies themselves cannot guarantee economic success. Policies must be implemented in a receptive social environment and public consensus must be achieved for the policies. Policies enacted in Japan achieved considerable acceptance by the

population because of Japan's homogenous population, displaying common social, religious and political beliefs.

In addition the Japanese policymakers strived to reach public consensus as to the need for policies enacted and the goals of such policies. Japan developed elaborate communications networks to achieve such consensus. The periodic publication of the white papers, "visions," economic plans and other information material by the Japanese government educated and informed Japan's population as to the need for policies.

In marked contrast French government policies were enacted without any attempt to educate and inform France's population as to the need for such policies. Further, unlike in Japan, the French population is fragmented among different political and social interest groups with conflicting goals and social values. The political and social fragmentation of France, intensified by several major changes in France's political philosophies and leadership since the end of World War II, created a certain hostility to the French government's policies.

Many of the French policies were enacted on behalf of the large French industrial enterprises controlled by the French government. The smaller and medium sized French industrial entities, not controlled by the government, were essentially neglected and developed opposition to these policies.

The German government did not interfere with free market functions in domestic or international markets on behalf of German industry. The cohesiveness of Germany society in general and the close cooperation between the German labour unions and the management of industrial entities, and between the industrial sectors and the German academic community significantly assisted Germany in achieving growth and technological advancement in domestic and international markets. The German performance in advanced technology sectors over recent decades has been modest when compared to that of Japan, but significantly more impressive than that of France. It can be concluded then for optimum economic advancement, appropriate government policies must be enacted within a socially and politically receptive environment.

c) A central element of classical economic theory was the importance of geographic factors in determining a nation's comparative advantage for a specific product. For many advanced technology industries, particularly microelectronics and machine tools, the simple fact is that geographic factors are of marginal relevance. This is manifest in a number of ways. Firstly and most obviously, a raw materials base and climatic factors are of little consequence in the production of microelectronics and machine tools. For these industries, geographic factors cannot determine comparative advantage. Thus Japan, possessing few, or no natural resources, was able to establish and maintain comparative advantages in both these sectors, primarily through the use of government policies.

On first examination the principal locus of industrial activities related to advanced polymers and advanced ceramics appears to be determined by the availability of resources (clay and oil) and therefore determined by geographic factors -- one of the principal industry location determinants of the classical economic theory. Thus, it could be argued that clay resources in Japan were the primary determinant of Japan's dominance of the advanced ceramics industry, while crude oil in the U.S. dictated the U.S. preeminence in the field of advanced polymers. However, it is important to note that the U.S. also possesses large resources of clay and that the U.S. tried and failed to develop its advanced ceramics industry during the later 1970's. This failure was a direct consequence of the U.S. government's unwillingness to intervene on behalf of this industry sector. Similarly, while advanced polymer industry may have originated in the U.S. due to crude oil resources, the continued world domination of this industry is due almost exclusively to the heavy investments made by the U.S. DOD.

Finally the importance of geographic boundaries has diminished considerably in the international trade of advanced technology products as a result of the ease with which technology (in the form of both know-how and finished products) can diffuse over geographic boundaries. Thus while most of the major breakthroughs that have occurred in the microelectronics and machine tools sector have been made outside Japan, Japan has been able to acquire the relevant

chnology with ease through licensing agreements or outright purchases. The emergence of multinational corporations has further eroded the significance of geographic boundaries, allowing companies to expand beyond the confines of their home country and to manufacture, market and sell products in numerous foreign markets simultaneously.

Taken together, these elements of the "new" economic theory present a challenge to current interpretations in economic geography. Furthermore, they influence profoundly a nation's economic base, an increasingly vital factor in the changing global geopolitical scene (Taylor, 1989).

FOOTNOTES TO CHAPTER 13

1 There exist several accepted categorizations of industrial nations with regard to technology policies. A well prepared statement of this can be found in a chapter prepared by Henry Ergas, a trade counsellor at the OECD, in the Guile and Brooke (1987) report on a recent symposium on technology and social priorities organized by U.S. National Academy of Engineering.

CHAPTER 14:

PROSPECTS

Analyses presented in this thesis suggest the emergence of Japan as a power in international economics and the relative decline of the U.S. The completed analyses also suggests only modest growth in advanced technology sectors in the principal European industrial nations.

It is not likely that these developments will continue at as rapid a pace. On the contrary, the on-going geopolitical forces will, most likely, modify or even change these developments and relationships. The potential for a number of possible changes exists, and for some of these changes the basis has already been established by the historical developments. To begin with, the emerging prospects for a reduction in NATO-Soviet Bloc tensions may reduce the need for military power in certain industrial nations. The possibility of a nation possessing geopolitical power without a military power base, has been, of course, proven by Japan. However, the reduction of a nation's industrial activities directly related to defence considerations may result in a reduction of research and development activities in many of the advanced technology areas. A nation such as the U.S., for example, may be required to adopt unprecedented policies to encourage research and development activities in advanced technology sectors that were in the past driven by defence considerations and defence funding.

The removal of the Soviet influence in Eastern Europe and the decreasing influence of Communism in the Soviet Union itself may open significant new markets for the non-Communist nations. It is very likely that these new markets will be the subject of competition between the U.S., Japanese and West-European nations.

The creation of the single European market in 1992 will also result in increased competition between the U.S., Japan and EC member nations. The relative absence of native advanced technology industries in the EC countries may initially preclude large sales of advanced technology products in the Common Market by native firms, but it is reasonable to expect that the EC nations will rectify this by arranging for appropriate linkages with Japan or the U.S. It is possible that a three-tier concentration of advanced technologies consisting of Japan, the U.S. and Common Market countries will evolve in a relatively short time period.

A market for advanced technology products significantly larger than that of the Soviet Union, Eastern Europe or the Common Market may be made available in China. It is reasonable to assume that Japan, because of its proximity and the already existing marketing effort there, may attempt to dominate this potential market. However some of the NICs should also be considered as competition to Japan if China's large potential market is opened to foreign nations.

Finally, it is also possible that the much talked about "Pacific Rim" country (Japan and NIC) collaboration will take place and will compete against the U.S. and Common Market countries in China, Eastern Europe, the Soviet Union and other areas of the world.

It should be pointed out that Japan is destined to play a major role as a world power in any of these changes. Japan's rapid economic growth combined with achievements in advanced technology sectors places Japan alongside the U.S. and the EC as a world power. Japan's potential influence over coming years is also assured by the successful Japanese efforts to penetrate the domestic economics of the EC nations, the U.S. and to establish an economic presence in NICs and less developed countries. Japanese firms have also been very successful in establishing close working relationships with the native firms in many industrialized nations. Japan is therefore well prepared to battle for dominance in the potential, future, markets of the USSR and China.

Any one or several of the above speculative developments may take place, and it is not prudent to assign probabilities to these possible developments at this time. It is likely however that any such developments will take place only if accompanied by appropriate policies by the governments involved to deliberately foster such developments.

APPENDIX A:

ACKNOWLEDGEMENTS

John A. Alic, Project Director
Office of Technology Assessment
United States Congress
Washington, DC 20510

Dr. Harvey E. Bale, Jr.
Deputy Assistant United States Trade
Representative for Trade Policy Development
Executive Office of the President
1800 G Street, NW
Washington, DC 20506

Iain S. Baird, Director
Priorities and Allocations Div.
Office of Industrial Mobilization
U.S. Department of Commerce
Washington, DC 20230

Dr. Sumner Benson, Deputy Director
Technology Cooperation and Security
Office of the Secretary of Defense
The Pentagon, IC469
Washington, DC 20301

Brad Bergmann, Director
Logistics Planning & Analysis
Office of the Asst. Secretary of Defense
(Production and Logistics)
Room 2D261, Pentagon
Washington, DC 20301

Col. Gordon L. Boozer, USAF
Senior Fellow
Mobilization Concepts Development Center
National Defense University
Washington, DC 20319

Allan C. Brittle
Assistant Director of Marketing
Emerson Electric Co.
8100 W. Forissant
St. Louis, MO 63136

Alan C. Chase
Professional Staff Member
House Armed Services Committee
U.S. House of Representatives
2339 Rayburn Building
Washington, DC 20515

John C. Clayton
Commission on Engineering and Technical Systems
National Research Council
National Academy of Sciences
National Academy of Engineering
2101 Constitution Avenue
Washington, DC 20418

Kenneth R. Foster
Staff Director, Materials Policy
Office of the Under Secretary of Defense
Research & Engineering
The Pentagon, Room 2A330
Washington, DC 20301

Otomi Fujii, Director
Electronic Devices Dept.
Electronic Industries Assoc. of Japan
Tokyo Chamber of Commerce & Industry Bldg.
2-2, 3-Chome Marunouchi
Chiyoda-Ku, Tokyo, JAPAN

Larry M. Hall
Industry Economist
Office of Resources Preparedness
FEMA
500 C Street, SW, Suite 617
Washington, DC 20472

John R. Heizer
General Physical Scientist
Office of Productivity
Technology & Innovation
U.S. Department of Commerce
Washington, DC 20230

Nelson J. Hogge, Analyst
U.S. International Trade Commission
701 E' Street, NW
Washington, DC 20436

David L. Husband, Director
Economic Impact Analysis
Overseas Private Investment Corporation
1129 Twentieth Street, NW
Washington, DC 20527

Hisao Kanamaru
Department Manager, Marketing and Planning
Electronic Devices Group
Hitachi, Ltd.
Nippon Building
No. 6-2, 2-Chome, Ohtemachi
Chiyoda-Ku, Tokyo 100, JAPAN

Frederick T. Knickerbocker
Office of the Secretary
U.S. Department of Commerce
Washington, DC 20230

Keith R. Knoblock, Vice President
American Mining Congress
1920 N Street NW, Suite 300
Washington, DC 20036

Takashi Kubo, Manager
Electronic Devices Dept.
Electronic Industries Assoc. of Japan
Tokyo Chamber of Commerce & Industry Bldg.
2-2, 3-Chome Marunouchi
Chiyoda-Ku, Tokyo, JAPAN

Richard B. Levine
Staff Member
National Security Council
The White House
Washington, DC 20300

Brian Mannix, Resident Fellow
Managing Editor, Regulation
American Enterprise Institute for
Public Policy Research
1150 17th Street, NW
Washington, DC 20036

George T. Marcou
Assistant to Director
Advanced Energy Programs
Westinghouse Electric Corporation
Power Systems Company
1801 K Street, NW
Washington, DC 20006

Martin L. Marimont
Assistant Director for Economic Accounts
Bureau of Economic Analysis -- BE-7
U.S. Department of Commerce
Washington, DC 20230

D. Bruce Merrifield
Assistant Secretary of Productivity
Technology and Innovation
U.S. Department of Commerce, Room 4824
14th & Constitution, NW
Washington, DC 20230

E. David Metz
Director, R&D Laboratories
5005 East McDowell Road
P.O. Box 2953
Phoenix, AZ 85062

Robert T. Miki
Deputy Assistant Secretary
for Regulatory Policy (Acting)
U.S. Department of Commerce, Room 7614
Washington, DC 20230

Egils Milbergs, Executive Director
President's Commission on Industrial Competitiveness
736 Jackson Place, NW
Washington, DC 20503

Yoshiyuki Miyatake, Manager
Strategic Marketing Research
Electron Device Group, Planning Office
NEC
33-7, Shiba Gochome, Minato-Ku
Tokyo 108, JAPAN

Gordon E. Moore, President
Intel Corporation
3065 Bowers Avenue
Santa Clara, CA 95051

William C. Mott, Executive Director
Council on Economics and National Security
1730 Rhode Island Ave., NW, Suite 709
Washington, DC 20036

Oystein Noreng
Research Director Research Centre
Institute of Energy Policy
Bendriftsokonomisk Institutt
Hans Burumsv. 30
1340 Bekkestua, NORWAY

Mike Norton
First Secretary (Science)
British Embassy
3100 Massachusetts Ave., NW
Washington, DC 20008

Eiji Ogu
Vice President and General Manager
Hitachi America, Ltd.
1800 Bering Drive
San Jose, CA 95112

George H. Orrell
Chief, Industrial Protection Division
Office of Civil Preparedness
FEMA
Federal Center Plaza
Donohoe Building -- Room 625
500 C Street, SW
Washington, DC 20472

James M. Owens
Director, Materials Division
Room 2007
Department of Commerce
Washington, DC 20230

Edith B. Page
Science, Education & Transportation
Office of Technology Assessment
Congress of the United States
Washington, DC 20510

Charles H. Phipps
Manager, Strategic Planning
Corporate Development
Texas Instruments
P.O. Box 5474
Dallas, TX 75222

David Price
Professional Staff
Committee on Armed Services
U.S. House of Representatives
420 Cannon Building
Washington, DC 20515

John A. Richards, Director
Office of Industrial Resource Administration
Department of Commerce, Room 4104
Washington, DC 20230

Emily H. Rock
Office of Policy Development
The White House
Washington, DC

Robert I. Scace, Deputy Director
Center for Electronics and
Electrical Engineering
National Bureau of Standards
Gaithersburg, MD 20899

David L. Schlechty
Director of Policy
Office of Export Administration
U.S. Department of Commerce
14th Street & Pennsylvania Ave., NW
Washington, DC 20230

Robert A. Silano, Faculty Member
External Programs Directorate
National Defense University
Fort Lesley J. McNair
Washington, DC 20319

Roman W. Sloniewsky
Deputy Assistant General Counsel
for Domestic Commerce
U.S. Department of Commerce
Washington, DC 20230

Miron L. Straf, Research Director
Committee on National Statistics
National Academy of Sciences
2101 Constitution Ave., NW
Washington, DC 20418

Larry W. Sumney
Manager, VHSI Circuit Program
Office of the Under Secretary of Defense
Research and Engineering
Department of Defense
Pentagon
Washington, DC 20301

Hiroo Taniguchi
General Manager, Eastern Sales Office
Mitsubishi Electronics America, Inc.
200 Unicorn Park Drive
Woburn, MA 01801

Gregory C. Tasse
Senior Economist, Planning Office
National Bureau of Standards
U.S. Department of Commerce
Washington, DC 20234

Anatoli Welihozkiy, Manager
Office of Foreign Availability
14th & Constitution Ave., Room SB701
Washington, DC 20230

Dr. Gerald T. West
Vice President for Development
Overseas Private Investment Corp.
1129 Twentieth Street, NW
Washington, DC 20527

Eugene R. White, Deputy Chairman
Amdahl Corporation
1250 East Arques Avenue
Sunnyvale, CA 94086

Hiroo Yoshie, Assistant to Group Executive
Semiconductor Group
Toshiba Corporation
72, Horikawa-Cho, Saiwai-Ku
Kawasaki, 210, JAPAN

APPENDIX B:

GLOSSARY

Access Time	The time interval between the instant that data is called from or delivered to a storage device (memory) and the instant the requested retrieval or storage is complete.
Algorithm	A prescribed set of well-defined rules for the solution of a problem. Algorithms are implemented on a computer by a stored sequence of instructions.
Analog	Indicates continuous, non-digital representation of phenomena. An analog voltage, for example, may take any value.
Artificial Intelligence (AI)	Artificial Intelligence. The capability of a computer to perform functions that are normally attributed to human intelligence, such as learning, adapting, recognizing, classification, reasoning, self-correction and improvement.
Assembly Robot	A robot designed, programmed, or dedicated to putting together parts into subassemblies or complete products.
Automated Handling System	System(s) used to automatically move and store parts and raw materials throughout the manufacturing process and to integrate the flow of work pieces and tools with the manufacturing process. In FMS's, the automated material handling system operates under computer control.
Automated Storage and Retrieval System	A high density rack storage system with rail running vehicles serving the rack structure for automatic loading and unloading. Vehicles interface with AVGS, car-on-track, towline or other conveyor systems for automatic storage and retrieval of loads. In FMS's, automated storage systems operate under computer control.
Automatic Licensing Procedure	As mandated by the Export Administration Amendments Act of 1985, a requirement that individual validated license applications for most exports to COCM nations must be approved automatically by Export Administration 15 working days after filing unless the applicant is notified that more time (not to exceed 15 additional working days) is required. At the end of the 15- (or 30-) working-day period, the

export is deemed to be licensed, even if no document or communication to that effect has been sent or received.

APT	Automatically Programmed Tools. One of the principal software languages used in computer-aided manufacturing to program numerically controlled machine tools.
Automation	The theory, art, or technique of making a process automatic, self-moving, or self-controlling.
Batch Manufacture	The production of parts in discrete runs or batches, interspersed with other production operations or runs of other parts.
Batch Processing	The technique of processing an entire group (batch) of similar or related jobs or input items on a system at one time without operator interaction. Contrast with interactive graphics system.
Binary	A system of numbers using 2 as a base in contrast to the decimal system which uses 10 as a base. The binary system requires only two symbols...0 and 1.
Bipolar	Refers to transistors formed with two (N- and P-type) semiconductor types.
Bit	A binary digit. A bit is the smallest unit of storage in a digital computer and is used to represent one of the two digits in the binary number system.
Byte	A set of contiguous binary bits, usually eight, which are operated on as a unit. A Byte can also be a sub-set of a computer word.
CPU	Central Processor Unit. That part of a computer that fetches, decodes, and executes program instructions and maintains status of results.
Chip	A small piece of a semiconductor material such as silicon on which an integrated circuit has been fabricated.
Competi- tiveness	The relative ability of firms located in a particular country to develop, produce, and market goods or services of a particular type in competition with firms in other countries. As used in this report, costs of production are the most

important single factor in determining competitiveness.

- CMOS Complementary Metal Oxide Semiconductor. A logic family made by combining N-channel and P-channel MOS transistors.
- CAD Computer-Aided Design. Describes the more demanding and elaborate preparation of complex schematics and blueprints, typically those of industry. In these applications an operator constructs a highly detailed drawing on-line using a variety of interaction device and programming techniques. Facilities are required for replicating basic figures; achieving exact size and placement of components; making lines of specified length, width, or angle to previously defined lines; satisfying varying geometric and topological constraints among components of the drawing; etc.
- CAD/CAM Computer-Aided Design/Computer-Aided Manufacturing. Refers to the integration of computers into the entire design-to-fabrication cycle of a product or plant.
- CAM Computer-Aided Manufacturing. The use of computer and digital technology to generate manufacturing-oriented data. Data drawn from a CAD/CAM database can assist in or control a portion or all of a manufacturing process, including numerically controlled machines, computer-assisted parts programming, computer-assisted process planning, robotics and programmable logic controls. CAM can involve production programming, manufacturing engineering, industrial engineering, facilities engineering and reliability engineering (quality control). CAM techniques can be used to produce process plans for fabricating a complete assembly; to program robots; and to coordinate plant operation.
- CIM Computer-Integrated Manufacturing. The concept of a totally automated factory in which all manufacturing processes are integrated and controlled by a CAD/CAM system. CIM enables production planners and schedulers, shop-floor foremen, and accountants to use the same database as product designers and engineers.

CNC	Computer Numerical Control. A technique in which a machine tool control uses a minicomputer to store NC instructions generated earlier by CAD/CAM for controlling the machining.
Controller	An information processing device whose inputs are both the desired and the measured position velocity or other pertinent variables in a process and whose outputs are drive signals to a controlling motor or actuator. The controller has a threefold function: first, to initiate and terminate motions of the manipulator in a desired sequence and at desired points; second, to store position and sequence data in memory; and third, to interface with the "outside world".
Country Groups	Seven groups of foreign countries, established by the U.S. Commerce Department for export control purposes. Canada is not included in any country group and is referred to by name in the Export Administration Regulations.
Dedicated Manufacturing System	A series of specially designed machine tools for automatically machining one part or several very similar parts in large quantities. An example would be a transfer line for machining automobile engine blocks.
Development System	Microcomputer system complete with peripherals, memory and software, used to write, compile, run and debug application programs for one or more target microprocessors.
Die	A single square or rectangular piece of semiconductor material into which a specific electrical circuit has been fabricated. Plural is dice. Also called a chip.
Diffusion	A method of doping or modifying the characteristics of semiconductor material by "baking" wafers of the base semiconductor material in furnaces with controlled atmospheres or impurity materials.
Digital	Refers to electronic circuits or devices, the inputs and outputs of which are nominally discrete voltage levels. Analog or linear circuits, in contrast, have inputs and outputs that vary continuously over a range of voltages. Virtually all computers process information in digital form.

DNC	Can stand for either Direct Numerical Control, in which a single computer operates a number of hardware or software controlled NC machines on a shared real time basis, or Distributed Numerical Control, in which a complete part program is downloaded to a CNC system from a central computer. There is an operator at each of the NC machine tools and the machines are handled in a normal autonomous mode.
Discrete	A semiconductor device containing only one active device, such as a transistor or a diode.
Dumping	The sale of exported goods at less than the price charged by the manufacturer in his home market, or in some cases at less than cost. Dumping is restricted under the GATT as an "unfair" trade practice.
Dynamic RAM	A type of semiconductor memory in which the presence or absence of a capacitive charge represents the state of a binary storage element. The charge must be periodically refreshed.
EAROM	Electrically Alterable ROM. A read-only memory whose contents may be altered on rare occasions through electrical stimuli.
EAPROM	Electrically-Erasable PROM.
Embargo	A legal prohibition on commerce.
End Use	The purpose or application for which controlled commodities or technical data will be used by a consignee.
EPROM	Erasable PROM. Similar to ROM, but enables the user to erase stored information and replace it with new information, when necessary. Most EPROMs are erased through exposure to ultra-violet light.
Flexible Automation	Refers to the multi-task capability of robots; multi-purpose, adaptable, reprogrammable.
FMC	Flexible Machining Center. Usually a multi-task capability of robots; multi-purpose, adaptable, reprogrammable.
FMS	Flexible Manufacturing System. Four or more NC machine tools having automatic tool changing and part handling capabilities at, and between, the machines and all under computer control. An FMS can operate on a number of different parts simul-

taneously without human interference for an extended time period, such as one or several shifts. An example would be a line of eight horizontal machining centres.

GATT	General Agreement on Tariffs and Trade. An international organization, based in Geneva, that provides a forum for trade negotiations. Member countries are committed to reducing the barriers to world trade, and expanding its volume.
HMOS	High performance MOS.
Hybrid Circuit	Any combination of two or more of the following in one package: * Active substrate integrated circuit. * Passive substrate integrated circuit. * Discrete component.
Input/Output	Relating to the equipment or method used for transmitting (I/O) information into and out of a computer.
Integrated Circuit (IC)	A semiconductor die containing multiple elements that act together to form the complete device circuit.
Intelligent Robot	A robot that can make sophisticated decisions and behavioral choices through its sensing and recognizing capabilities.
IGS ICG	Interactive Graphics System or Interactive Computer Graphics. A CAD/CAM system in which the workstations are used interactively for computer-aided design and/or drafting, as well as for CAM, all under full operator control, and possibly also for text-processing, generation of charts and graphs, or computer-aided engineering. The designer (operator) can intervene to enter data and direct the course of any program, receiving immediate visual feedback via the CRT. Bilateral communications are provided between the system and the user(s). Often used synonymously with CAD.
Interface	(1) A hardware and/or software link which enables two systems, or a system and its peripherals, to operate as a single; integrated system. (2) The input devices and visual feedback capabilities which allow bilateral communication between the user and the system.

ITC	International Trade Commission. An independent agency of the U.S. Government which investigates and rules on trade-related matters, primarily concerned with imports.
Keystone Equipment	Sophisticated devices essential to the successful operation/completion of manufacturing processes. (Some examples include process control equipment and specialized machine tools).
LED	Light Emitting Diode. A semiconductor device that emits light whenever current passes through it.
LSI	Large Scale Integration. LSI devices contain 100 or more gate equivalents or other circuitry of similar complexity.
Linear IC	An analog integrated circuit, as opposed to a digital integrated circuit.
Machining Centre	A machine capable of performing a variety of metal removal operations on a part, usually under numerical control.
Manipulator	The mechanical linkages or joints of a robot or machine tool which move in prescribed directions in order to move parts, tools or materials.
Mask	A patterned screen, usually of glass, used to expose selected areas of a semiconductor (that has been covered with a photoresist) to a light source that causes polymerization.
MOS	Metal Oxide Semiconductor. Devices using FETs in which current flow through a channel of N- or P-type semiconductor material is controlled by the electric field around a gate structure. MOSFETs are unipolar devices characterized by extremely high input resistance.
MSI	Medium Scale Integration. ICs containing ten or more gate equivalents but less than 100.
Micro-computer	A microprocessor complete with stored program memory (ROM), random access memory (RAM), and input/output (I/O) logic. If all functions are on the same chip, this is sometimes called a microcontroller. Microcomputers are capable of performing useful work without additional supporting logic.

Micro-electronics	Microscopically small components or circuits made by means of photolithography techniques.
Micron	Synonymous with micrometer: one millionth of a meter.
Micro-processor	Computer central processing unit on a single chip.
Minicomputer	A class of computer in which the basic element of the central processing unit is constructed of a number of discrete components and integrated circuits rather than being comprised of a single integrated circuit, as is the microprocessor.
Module	A separate and distinct unit of hardware or software which is part of a system.
Monolithic Device	A device whose circuitry is completely contained on a single die or chip.
Multilateral	As used in this report, referring to agreements or negotiations among three or more nations to reach common accord on national security export controls and procedures.
Network	An arrangement of two or more interconnected computer systems to facilitate the exchange of information in order to perform a specific function. For example, a CAD/CAM system might be connected to a mainframe computer to off-load heavy analytic tasks. Also refers to a piping network in computer-aided plant design. "Local networking" is the communications network internal to a robot. "Global networking" is the ability to provide communications connections outside of the robot's internal system.
Non-Servo Robot	A robot that can be programmed by its motions only to the end points of each of its axes of motion. See robot, servo-robot.
NC	Numerical Control. A technique of operating machine tools or similar equipment in which motion is developed in response to numerically coded commands. These commands may be generated by a CAD/CAM system on punched tapes or other communications media. Also, the processes involved in generating the data or tapes necessary to guide a machine tool in the manufacture of a part.

Offshore Manufacture	The production of parts and components, and/or their assembly, in plants located in foreign countries, followed by shipment back to the home market or to third country markets.
OECD	Organization for Economic Cooperation and Development. An international organization composed of industrial countries. Its aims are to encourage economic growth and employment and to promote the development of industrializing countries.
Peripherals	Computer hardware other than the processing unit itself. Typical peripherals are terminals, card readers, and auxiliary storage units.
Process	A systematic sequence of operations to produce a specific result.
Processor	The portion of a computer system that executes the program.
Process Planning	Specifying the sequence of production steps from start to finish, and describing the state of the workpiece at each workstation. Recently CAM capabilities have been applied to the task of preparing process plans for the fabrication or assembly of parts.
Programmable Controller	A programmable controller is a solid-state control system that can be programmed to execute instructions that control machines and process operation by implementing specific functions such as logic control, sequencing, timing, counting, and arithmetic operations. A programmable controller consists of five basic elements: (1) central processing unit; (2) memory; (3) input/output interface; (4) power supply; and (5) programming device.
PLA	Programmable Logic Array. A general purpose logic circuit containing an array of logic gates which can be connected (programmed) to perform various functions.
PROM	Programmable Read Only Memory. A read-only memory which can be programmed after manufacture by external equipment. Typically, PROMs utilize fusible links which may be burned open to produce a logic bit in a specific location.

RAM	Random Access Memory, which stores digital information temporarily and can be changed by the use. It constitutes the basic storage element in a computer. Also called a read/write memory.
ROM	Read Only Memory, which permanently stores information used repeatedly - such as microcode or characters for electronic display. Unlike RAM, ROM cannot be altered.
Real Time	Refers to tasks or functions executed so rapidly by a CAD/CAM system that the feedback at various stages in the process can be used to guide the user completing the task.
Reexport	The exportation of commodities or technical data from one foreign destination to another at any time after initial export from the country of origin.
Reverse Engineering	Reproduction of a unique product based solely on examination and analysis of a sample of the product.
Robot	A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks.
Robot Motions	Four types of work motions: (1) Anthropometric Motion - Motion of a robot as in a shoulder, elbow and a wrist, developing a modified spherical work envelope. (2) Cylindrical Motion - the motion of a robot's arm when mounted on cylindrical axis. (3) Polar Motion - the motions of a robot by two axes of rotation which create a modified spherical work envelope. (4) Rectilinear Motion - motions of a robot in three dimensions along straight lines.
Robotics	The use of computer-controlled manipulators or arms to automate a variety of manufacturing processes such as welding, material handling, painting, and assembly.
Semi-conductor	A material with properties of both a conductor and an insulator. Common semiconductors include silicon and germanium.
Sensor	A transducer or other device whose input is a physical phenomenon and whose output is a quantitative measure of that physical phenomenon.

Servo- Controlled Robot	A robot driven by servomechanisms, i.e., motors whose driving signal is a function of the difference between commanded position and/or rate and measured actual position and/or rate. Such a robot is capable of stopping at or moving through a practically unlimited number of points in executing a programmed trajectory.
Servo- mechanism	A control system for the robot in which the computer issues commands, the air motor drives the arm, and a sensor measures the motion and signals the amount of the motion back to the computer. This process is continued until the arm is repositioned to the point requested.
Servo-Robot	A robot whose manipulator can be commanded to move anywhere within its limits of grasp (any points along its axis of motion). See non-servo robot.
Software	Computer program. Can also refer to other carriers of information such as books, film, phonograph records.
Start-up	The time between the installation and the final operation of the system as desired.
Static RAM	A type of RAM which does not require periodic refresh cycles, as does dynamic RAM.
Technical Data	Information of any kind that can be used or adapted for use in the design, production, manufacture, utilization, or reconstruction of articles or materials. The data may take a tangible form, such as a model, prototype, blueprint, or an operating manual (the tangible form may be stored on recording media); or they may take an intangible form such as technical know-how. Software is considered technical data.
Technological Commodity	Mass-produced items that are marketed, distributed, and/or warehoused in large quantities for use by distributors and customers around the world. Most items that can be purchased from retail outlets on a cash-and-carry basis are also technological commodities. Examples of commodities currently subject to national security export controls are some personal computers and related peripheral devices, floppy discs, and microchips.
Technology Transfer	In the context of this report, the acquisition by one country from another of products, technology, or know-how that directly or indirectly enables a

qualitative or quantitative upgrading of deployed military systems or the development of effective countermeasures to military systems deployed by others.

Third Countries	Free World nations that are not members of COCOM.
Tool	A term used loosely to define something mounted on the end of a robot arm, e.g., a hand, a gripper, or an arc welding torch.
Transistor	The basic solid-state device used to amplify or switch electrical current.
Transshipment	The transfer, by a series of separately documented shipments, of controlled products through one or more countries en route to a final destination that may be a proscribed country. Initially, the final destination - and in later transactions, the country of origin - are concealed to avoid export or re-export prohibitions.
Turnkey	A CAD/CAM or robotic system for which the supplier/vendor assumes total responsibility for building, installing, and testing both hardware and software, and the training of user personnel. Also loosely, a system which comes equipped with all the hardware and software required to do a specific application or applications. Usually implies a commitment by the vendor to make the system work, and to provide preventative remedial maintenance of both hardware and software. Sometimes used interchangeably with stand alone, although stand alone applies more to a system's architecture than to terms of purchase.
Vertical Integration	A method of manufacturing a product, such as a CAD/CAM system, whereby all major modules and components are fabricated in-house under uniform company quality control and fully supported by the system vendor.
VHSIC	Very High-Speed Integrated Circuit. Name given to a U.S. Department of Defense R&D program aimed at military needs for VLSI circuits. The designation refers to the high speed required for applications such as signal processing.
VLSI	Very Large Scale Integration. VLSI devices are ICs that contain 1,000 or more gate equivalents.

Wafer

A thin disk of semiconducting material (usually silicon) on which many separate chips can be fabricated and then cut into individual ICs. Also called a slice.

APPENDIX C:

BIBLIOGRAPHY

Abelson, Philip H. "Improving U.S. Capabilities in Technology." Science 28 (October 1988): 493.

Abernathy, W.J. and R.S. Rosenbloom. "The Institutional Climate for Innovation in Industry: The Role of Management Attitudes and Practices", The 5-Year Outlook for Science and Technology 1981: Source Materials, Volume 2. NSF 81-42. Washington, DC: National Science Foundation, 1981.

Adams, F. Gerard and Lawrence R. Klein, eds. Industrial Policies for Growth and Competitiveness: An Economic Perspective. Wharton Econometric Studies Series. Lexington, MA and Toronto: Heath, Lexington Books, 1983.

Adams, F. Gerard, Martin Cherkes and Robert F. Wescott. Innovation, Technical Progress, and Industrial Policy: A Survey. Wharton Econometric Studies Series. Lexington, MA and Toronto: Heath, Lexington Books, 1983.

Adams, F. Gerard and Lawrence R. Klein. Economic Evaluation of Industrial Policies for Growth and Competitiveness: Overview. Wharton Econometric Studies Series. Lexington, MA and Toronto: Heath, Lexington Books, 1983.

Advisory Board for the Research Councils. Scientific Opportunities and the Science Budget 1983: A Report to the Secretary of State for Education and Science. London: ABRC, 1984.

Aggarwal, Raj. "Investment Performance of Based Multinational Companies: Comment on a Perspective on International Diversification Real Assets." J. Int. Bus. Stud., 11, 1 (Spring/Summer 1980): 98-104.

Agency of Industrial Science and Technology/Ministry of International Trade and Industry. National Research and Development Program (Large-Scale Project). Japan: AIST/MITI, 1983.

Agency of Industrial Science and Technology. Trends of Principal Indices on Research and Development Activities in Japan. Japan: AIST/General Coordination Department, Technology Research and Information Division, April 1981.

Agmon, Tamir. Political Economy and Risk in World Financial Markets. Lexington, MA: Lexington Books, 1985.

Albus, J.S., A.J. Barbera, M.L. Fitzgerald, R.N. Nagel, G.J. Vanderbrug and T.E. Wheatley. "Measurement and Control Model for Adaptive Robots." Proceedings, 10th International Symposium on Industrial Robots, Milan, Italy, March 1980.

Alcock, Norman Z. and Alan Newcombe. "The Perception of National Power." Journal of Conflict Resolution 14 (1970).

Aldcroft, D.H. and H.W. Richardson. The British Economy, 1870-1939. London: Macmillan, 1970.

Allen, T., et al. "Government Influence on the Process of Innovation in Europe and Japan." Research Policy, 7 (1978): 124-149.

American Ceramic Society Bulletin. "Japan Issue," 61, 9 (1982): 915-938.

Amsden, Alice H. "Trade in Manufactures Among Developing Countries." The Economic Journal (1976): 86.

Anderson, Alun M. Science and Technologies in Japan: Longman Guide to World Science and Technology. Harlow, Essex: Longman, 1984.

Angelmar, R. "Market Structure and Research Intensity in High-Technological-Opportunity Industries." J. Ind. Econ. 34 (1985): 69-79.

Aquino, Antonio. "Intra-Industry Trade and Inter-Industry Specialization as Concurrent Sources in International Trade in Manufactures." Welwirtsch. Arch., 114, 2 (1983): 275-296.

Arcangeli, Fabio; Dosi, Giovanni and Moggi, Massimo. "The Patterns of Diffusion of Microelectronic Technologies." DRC Discussion Paper, SPRU, U. of Sussex, Brighton. Presented at the Conference on Programmable Automation, Paris, April 1987.

Armour, Henry Ogden and David J. Teece. "Vertical Integration and Technological Innovation." Rev. Econ. Statist., 62, 3 (1980): 470-474.

Arnold, E. "Policies for Electronics, Computing and the Information Technologies in Four Smaller OECD Economies: Belgium, Canada, the Netherlands and Switzerland." A report to the National Swedish Board for Technical Development, Brighton SPRU, 1986.

Aron, Paul. "Robotics Revisited." In Social Impacts of Robotics. Washington, DC: Office of Technology Assessment, February 1982.

Asher, Norman J. and Leland D. Strom. The Role of the Department of Defense in the Development of Integrated Circuits. Arlington, VA: Institute for Defense Analyses, May 1977.

Auquier, Antoine A. "Sizes of Firms, Exporting Behavior, and the Structure of French Industry." J. Ind. Econ. 29, 2 (December 1980): 203-218.

Auquier, A.A. "Industrial Organization in an Opening Economy: French Industry and the Formation of the European Common Market." Ph.D. dissertation, Harvard University, 1977.

Bailey, E. "Britain's Role at Ailing ICC." New York Times, 18 May 1981.

Baily, Martin W. and Chakrabarti, A.K. "Innovation and Productivity in U.S. Industry." Brookings Pap. Econ. Act., 2 (December 1985): 609-32.

Balassa, Bela. "Intra-Industry Specialization: A Cross-Country Analysis." Europ. Econ. Rev. 30, 1 (February 1986): 27-42.

Balassa, Bela. "French Industrial Policy Under the Socialist Government." Amer. Econ. Rev. 75, 2 (May 1985): 315-319.

Balassa, Bela. "The Changing Pattern of Comparative Advantage in Manufactured Goods." Review of Economics and Statistics 61, 2 (May 1979): 259-266.

Balcerowicz, Leszek. "Organizational Structure of the National Economy and Technological Innovations." Acta Oecon. 24, 1-2 (1980): 151-167.

Baldwin, David A. "Power Analysis and World Politics: New Trends Versus Old Tendencies." World Politics 3 (1979).

Baranson, J. "Technology Transfer Through the International Firm." American Economic Review LX (May 1983).

Barfield, Claude. "It's Still High Definition Intervention." The Wall Street Journal, 8 May 1989.

Baumol, William J. "Is There a U.S. Productivity Crisis." Science 243 (3 February 1989): 611.

Batra, R.N. and F.R. Casas. "Intermediate Products and the Pure Theory of International Trade: A Neo-Heckscher-Ohlin Framework." American Economic Review (June 1973): 297-311.

Batra, Raveendra N. and Rama Ramachandran. "Multinational Firms and the Theory of International Trade and Investment." Amer. Econ. Rev. 70, 3 (June 1980): 278-290.

Bement, A.L., Jr. "The Greening of Materials Science and Engineering." American Society for Metals and the Metallurgical Society Joint Distinguished Lecture in Materials and Society. Materials Week--1986, Orlando (7 October 1986).

Bergsten, C. Fred. The International Economic Policy of the United States: Selected Papers of C. Fred Bergsten, 1977-1979. Lexington, MA and Toronto: Heath, Lexington Books, 1980.

Bhagwati, Jagdish N. "International Factor Movements and National Advantage." Indian Econ. Rev. 14, 2 (October 1979): 73-100.

Bhagwati, Jagdish N. Essays in International Economic Theory, Volume 1: The Theory of Commercial Policy. Edited by Robert C. Feenstra. Cambridge, MA and London: MIT Press, 1983, pp. 97-109.

Bhagwati, Jagdish N. Essays in International Economic Theory, Volume 2: International Factor Mobility. Edited by Robert C. Feenstra. Cambridge, MA and London: MIT Press, 1983, pp. 3-30.

Bhagwati, Jagdish N. and Richard A. Brecher. "National Welfare in an Open Economy in the Presence of Foreign-Owned Factors of Production." J. Int. Econ. 10, 1 (February 1980): 103-115.

Bhattacharya, G. "Technology Transfer, Licensing and the Speed of Endogenous Technological Change." J. Econ. Dynam. Control 9, 4 (December 1985): 423-456.

Bide, A. (Chairman). Information Technology: the National Resource, A Plan for Concerted Action. Report of the IT86 Committee. London: HMSO, 1986.

Blackaby, Frank, ed. De-industrialization. National Institute of Economic and Social Research, Economic Policy Papers, no. 2. London: Heinemann Educational Books, 1979.

Blank, S. "Britain: The Politics of Foreign Economic Policy, the Domestic Economy, and the Problem of Pluralistic Stagnation." Between Power and Plenty: Foreign Economic Policies of Advanced Industrial States. Madison: University of Wisconsin Press, 1978.

Blumenthal, Tuvia. "A Note on the Relationship Between Domestic Research and Development and Imports of Technology." Econ. Develop. Cult. Change 27, 2 (January 1979): 303-306.

Blumenthal, W. Michael. "The World Economy and Technology Change." Foreign Affairs, 66, 3 (1988): 529-550.

Board of Trade. The Machine Tool Industry. A Report by the Subcommittee of the Machine Tool Advisory Council appointed to consider Professor Melman's Report to the European Productivity Agency. London, HMSO, 1960.

Boddewyn, Jean J. "Theories of Foreign Direct Investment: A Classification Note." Management International Review 25, 1 (1985): 57-65.

Boretsky, M. "The Threat to U.S. High Technology Industries: Economic and Security Implications" (Draft). International Trade Administration, U.S. Department of Commerce, 1982.

Borrus, Michael, Jan Millstein and John Zysman. International Competition in Advanced Industrial Sectors: Trade and Development in the Semiconductor Industry. Prepared for the Joint Economic Committee of the U.S. Congress. Washington, DC: U.S.G.P.O., 1982.

Bowen, Harry P. "Resources, Technology and Dynamic Comparative Advantage: A Cross-Country Analysis of the Product Cycle Theory of International Trade." Doctoral Dissertation, University of California, Los Angeles, 1980.

Bowen, Harry P. "Changes in the International Pattern of Factor Abundance and the Composition of Trade: A Multicountry Analysis of Changing Comparative Advantage in Manufactured Goods with Special Reference to the United States." Office of Foreign Economic Research, Bureau of International Labor Affairs, U.S. Department of Labor, 1980.

Brander, James A. and Barbara J. Spencer. "Strategic Commitment with R&D: The Symmetric Case." Bell J. Econ. 14, 1 (Spring 1983): 225-235.

Brander, James A. and Barbara J. Spencer. "Export Subsidies and International Market Share Rivalry." J. International Economics 16 (May 1984): 227-242.

Branscomb, Lewis. "Improving R&D Productivity: The Federal Role." Science (14 October 1983): 222.

Braun, Ernest and Stuart MacDonald. Revolution in Miniature: The History and Impact of Semiconductor Electronics. New York: Cambridge University Press, 1978.

Brech, M. and M. Sharp. Inward Investment - Policy Options for the United Kingdom. Chatham House Paper No. 21. London: Routledge Kegan Paul, 1984.

Brecher, R.A. "Optimal Policy in the Presence of Licensed Technology from Abroad." J. Political Economy 90 (1982): 1070-1078.

Bright, J.R. "Technological Forecasting as an Influence on Technological Innovation: Past Examples and Future Expectations." In Industrial Innovation. Edited by M.J. Baker. Macmillan, 1979.

Brinkman, William F. "Comparative R&D Ventures: Collaboration in the Semiconductor Industry." In Industrial R&D and U.S. Technological Leadership. National Academy Press, Washington, D.C. 1988.

Buckley, Peter J. and Mark Casson. The Economic Theory of the Multinational Enterprise. London and Basingstoke: Macmillan, 1985.

Bulmer, Simon. "Domestic Policies and European Community Policy-Making." J. Common Market Stud. 21, 4 (June 1983): 349-363.

Burns, J. "International Siting Priorities for a High Technology Firm." Ind. Develop. 153 (1984): 10-12.

Burn, D. ed. The Structure of British Industry. Cambridge, 1958.

Buswell, R.J. and E.W. Lewis. "The Geographical Distribution of Industrial Research Activity in the United Kingdom." Regional Studies 4 (1970): 297-306.

Busy, J.F. "Semiconductor Industry Challenges in the Decade Ahead." IEEE Solid State Circuits Conference, San Francisco, CA, 13-15 February 1980.

Cabinet Office. "Annual Review of Government Funded R&D." London: HMSO, annual.

Cabinet Office, Advisory Council for Applied Research and Development. "The Applications of Semiconductor Technology." HMSO, 1978.

Cameron, R., ed. Essays in French Economic History. Homeward, Ill.: R.D. Irwin for the American Economic Association, 1970.

Cannon, C.M. "International Trade, Concentration and Competition in U.K. Consumer Markets." Oxford Economic Papers 30 (1978).

Carter, Ashton B. and B.R. Williams. Industry and Technical Progress; Factors Governing the Speed of Application of Science. London: Oxford University Press, 1957.

Casson, Mark C. "Transaction Costs and the Theory of the Multinational Enterprise." In New Theories of the Multinational Enterprise. Edited by Alan M. Rungman. London: Croom Helm and New York: St. Martin's Press, 1982.

Casson, Mark. "General Theories of the Multinational Enterprise: A Critical Examination." Discussion Papers in International Investment and Business Studies. No. 77 University of Reading, 1984.

Caves, Richard E. "Causes of Direct Investment: Foreign Firms' Shares in Canadian and U.K. Manufacturing Industries." Review of Economics and Statistics 56 (1974): 279-293.

Caves, Richard E. Multinational Enterprise and Economic Analysis. Cambridge: Cambridge University Press, 1982.

Chavaron, J.J. "French Science Policy and Local High Tech Industries." Science and Public Policy 16 (February 1989): 317-362.

Chandler, Alfred D., Jr. "The Growth of the Transnational Industrial Firm in the United States and the United Kingdom: A Comparative Analysis." Econ. Hist. Rev., 2nd Ser., 33, 3 (August 1980): 396-410.

Charles, Daniel. "Can the Pentagon Fight Trade Wars." Science (12 August 1988).

Charles River Associates, Inc. "Innovation, Competition and Government Policy in the Semiconductor Industry." Boston, MA, 1980.

Charles River Associates, Inc. "The Effect of Government Policy on Innovation, Competition, and Performance: A Case Study of the Semiconductor Industry." Boston, MA, 1980.

Charles River Associates, Inc. Productivity Impacts of Government R&D Laboratories: The National Bureau of Standards' Semiconductor Technology Program. 2 Volumes. Boston: CRA, 1981.

Cheng, L. "Protection of 'High Technology' Industries, Counter-vailing Subsidies, and Welfare." Department of Economics, University of Florida, Gainesville, 1983. (Mimeographed.)

Cheng, L. "International Competition in R&D and Technological Leadership: An Examination of the Posner-Hufbauer Hypothesis." J. Int. Econ. 17, 1/2 (August 1984): 15-40.

Chipman, J.S. "Induced Technical Change and Patterns of International Trade." In The Technology Factor in International Trade. Edited by R. Vernon. New York: NBER, 1970.

Clark, Lindley H. and Alfred L. Malabre, Jr. "Eroding R&D." Wall Street Journal (16 November 1988).

Cline, Ray. World Power Trends and U.S. Foreign Policy for 1980's. New York: Westview Press, 1980.

Cline, William R., ed. Trade Policy in the 1980s. Washington, DC: Institute for International Economics. (Distributed by the MIT Press, Cambridge, MA and London, 1983) pp. 639-671.

Commission of the European Communities. The European Machine Tool Industry. SEC 83, 151, Brussels (February 1983).

Congressional Budget Office. Federal Support for R&D and Innovation. Washington, DC: CBO, April 1984.

Congressional Budget Office. Federal Financial Support for High Technology Industries. Washington, D.C.: CBO, 1985.

Connolly, R.A. and M. Hirschey. "R&D Market Structure, and Profits: A Value-Based Approach." Rev. Econ. Statist. 66, 4 (November 1984): 682-686.

Contractor, Farok J. "The Profitability of Technology Licensing by U.S. Multinationals: A Framework for Analysis and an Empirical Study." J. Int. Bus. Stud. 11, 2 (Fall 1980): 40-63.

Contractor, Farok J. "The Composition of Licensing Fees and Arrangements as a Function of Economic Development of Technology Recipient Nations." J. Int. Bus. Stud. 11, 3 (Winter 1980): 47-62.

Coomans, G. "Note sur la transnationalisation de l'economie belge" ("Note on the Transnationalisation of the Belgian Economy", with English summary). Econ. Soc. 19, 4 (April 1985): 141-159.

Coughlin, Cletus C. "The Relationship Between Foreign Ownership and Technology Transfer." J. Compar. Econ. 74, 4 (December 1983): 400-414.

Crafts, N.F.R. "Economic Growth in Britain and France, 1830-1910: A Review of the Evidence." J. Economic History 44 (1984): 49-68.

Crafts, N.F.R. and M. Thomas. "Comparative Advantage in UK Manufacturing Trade, 1910-1935." Econ. J. 96, 383 (September 1986): 629-645.

Crawford, Mark. "Applied R&D Key for U.S. Trade." Science (16 September 1988).

Cuneo, P. and J. Mairesse. "Productivity and R&D at the Firm Level in French Manufacturing." NBER Working Paper No. 1068, 1983.

Curren, T.J. "Politics and High Technology: The NTT Case." Coping With U.S.-Japanese Economic Conflicts. Lexington, MA: Lexington Books, 1982.

Dahlman, C.J. and F.C. Sercovich. "Exports of Technology from Semi-Industrial Economies and Local Technological Development." Journal Devel. Econ. 16, 1-2 (September-October 1984): 63-99.

Daly, A. and D.T. Jones. "The Machine Tool Industry in Britain, Germany and the United States." National Institute Economic Review 92 (May 1980): 53-63.

Daly, A., D. Hitchens and K. Wagner. "Productivity, Machinery and Skills in a Sample of British and German Manufacturing Plants." National Institute Economic Review (February 1985): 48-61.

Dalyell, Tam. A Science Policy for Britain. London: Longman, 1983.

Daniel, Charles. "Semiconductor Prospects." Science (3 August 1988).

Danzin, Andre. Science and the Second Renaissance of Europe. Oxford: Pergamon Press, 1979.

Das, D.K. "Management of U.S. Trade in Technology." J. World Trade Law 19, 1 (January/February 1985): 80-82.

Dasgupta, P. and J.E. Stiglitz. "Uncertainty, Industrial Structure and the Speed of R&D." Bell Journal of Economics (1980): 1-28.

Davidson, William H. and D.G. McFetridge. "International Technology Transactions and the Theory of the Firm." J. Ind. Econ. 32, 3 (March 1984): 253-264.

Davis, L.A. "Technology Intensity of U.S. Output and Trade." Office of Trade and Investment Analysis, U.S. Department of Commerce, July 1982.

Dean, Edwin, Harry Boissevain and James Thomas. "Productivity and Labor Costs Trends in Manufacturing, 12 Countries." U.S. Department of Labor, Bureau of Labor Statistics. Monthly Labor Review (March 1986): 3-10.

Deardorff, Alan V. "The General Validity of the Law of Comparative Advantage." J. Political Economy 88 (1980): 941-957.

de Carmoy, G. "Subsidy Policies in Britain, France and West Germany: An Overview." In International Trade and Industrial Policies. Edited by S.J. Warnecke. New York: Holmes & Meier, 1978.

- Deich, Ingrid. "The Redistribution of Authority in National Laboratories in Western Germany." Minerva XVII, 3 (Autumn 1979): 413-444
- Dennicoff, M. Robotics in Japan. Washington, DC: Office of Naval Research, 1982.
- Deutsch, Karl W. The Nerves of Government. New York: Free Press, 1963.
- Dickson, David. "CERN: Adapting to Middle Age." Science (4 September 1987): 237.
- Dickson, David. "Toward an Academia Europea?" Science (4 September 1987): 237.
- Dickson, David and Colin Norman. "Science and Mutual Self-Interest." Science (4 September 1987).
- Dickson, K. "The Influence of MoD Funding on Semiconductor Research and Development in the U.K." Research Policy (April 1983).
- Dickson, Keith and John Marsh. "The Microelectronics Revolution: A Brief Assessment of the Industrial Impact with a Selected Bibliography." Technology Policy Unit, University of Aston in Birmingham, 1978.
- Diodati, J. "Vertical Integration as a Determinant of Industry Performance in the Telecommunications Industry." European Association for Research in Industrial Economics, 1980. (Mimeographed.)
- Dixit, Avinash K. and Albert S. Kyle. "On the Use of Trade Restrictions for Entry Promotion and Deterrence." Woodrow Wilson School Discussion Papers in Economics No. 56, Princeton University, 1983.
- Dixit, A.K. and A.S. Kyle. "The Use of Protection and Subsidies for Entry Promotion and Deterrence." American Economic Review 75 (1985): 139-152.
- Dosi, Giovanni. "Technical Change and Survival: Europe's Semiconductor Industry." Sussex European Papers No. 9, University of Sussex, 1981.
- Dosi, Giovanni. "Technological Paradigms and Technological Trajectories: the Determinants and Direction of Technical Change and the Transformation of the Economy." In Long Waves in the World Economy. Edited by C. Freeman. London: Frances Pinter, 1983, Chapter 7.
- Dosi, Giovanni. Technical Change and Industrial Transformation: The Theory of Application to the Semiconductor Industry. New York: Macmillan, 1984.

Dosi, Giovanni. "Sources, Procedures, and Microelectronic Effects of Innovation." J. Economic Literature (September 1988): 1120-1171.

Dunning, John H. "Trade, Location of Economic Activity and the MNE: A Search for an Eclectic Approach." In The International Allocation of Economic Activity: Proceedings of a Nobel Symposium Held at Stockholm. Edited by Bertil Ohlin, Perove Hesselborn and Per Magnus Wijkman. London: Macmillan, 1977, pp. 395-431.

Dunning, John H. International Production and the Multinational Enterprise. London: George Allen & Unwin, 1981.

EC Commission. "Industrial Specialization in 12 European Countries Before and After 1973." Luxembourg, 1980.

EC Commission. "Industrial Policies in the Community: State Intervention and Structural Adjustment." Brussels, 1981.

Economist, The. "Chips and Bugs: Tiny Technologies with a Big Future." (13 November 1979): 62-64.

Economist, The. "Les Miserables." (10 December 1988): 86-83.

Economist, The. "Technology the French Way." (17 November 1984): 94-95.

Economist, The. "The Agency Young Pretender." (10 December 1988): 121-127.

Economist, The. "Stand Back Whitehall." (14 January 1989): 16-17.

Economist, The. "The Final Thrust." (18 March 1989): 21-23.

El-Agraa, A.M., ed. The Economics of the European Community. New York: St. Martin's Press, 1980; 2nd edition, Oxford, 1985.

Ellis, Doreen. "European Industrial Policies: Balancing Independence and Interest." Ann. Amer. Acad. Polit. Soc. Sci. 440 (November 1978): 122-34.

English, Maurice and Adam Watson Brown. "Japanese National Actions in I.T." Commission of the European Communities, Information Technology Task Force, Draft Eight, July 1984.

Ergas, H. "Why do Some Countries Innovate More than Others?" CEPS Paper No. 5. Brussels: Centre for European Policy Studies, 1984.

Etzkowitz, Henry. "Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science." Minerva XXI, 2-3, (Summer/Autumn 1983): 198-233.

European Commission. "Forecasting and Assessment in Science and Technology (FAST) Report, Volume 1 - Results and Recommendations; Volume 2 - Summaries of 36 Research Projects." Brussels: Commission of the European Communities, 1983.

European Economic Community. "COST European Cooperation in the Field of Scientific and Technical Cooperation." General Resolution of the Ministerial Conference for European Cooperation in the Field of Scientific and Technical Research, Brussels, 22-23 November 1971.

European Economic Community. "The European Public's Attitude to Scientific and Technical Development." Opinion poll in the countries of the European Community, Commission, Brussels, 1979.

European Economic Community. Towards a European Technology Community. Brussels: EEC, June 1980, p. 50.

European Economic Community. "Community Inter-Institutional Information System (INSIS)." Council Decision of 28 July 1982, OJ No. L247 of 23 August 1982.

European Economic Community. "Eurotra Machine Translation System of Advanced Design." Council Decision of 4 November 1984, OJ No. L317 of 13 November 1982.

European Economic Community. "Committee for the European Development of Science and Technology (CODEST)." Commission Decision of 6 December 1982, OJ No. L350 of 10 December 1982.

European Economic Community. Community Scientific and Technical Strategy: Seven Major Goals for 1984-87. Brussels: EEC, May 1983, p. 41.

European Economic Community. "Framework Programme 1984-1987 for a European Scientific and Technical Strategy." Council Resolution of 25 July 1983, OJ No. C208 of 4 August 1983.

European Economic Community. "Community Action Programme in Education and Training for Technology (COMETT)." Council Resolution of 19 September 1983, OJ No. C256 of 24 September 1983.

European Economic Community. "Research Programme of the European Economic Community on Forecasting and Assessment in Science and Technology (FAST) 1983-1987." Council Decision EEC/83/519 of 17 October 1983, OJ No. L293 of 25 October 1983.

European Economic Community. "European Strategic Programme for Research and Development in Information Technology (ESPRIT)." Council Decision 84/130/EEC of 28 February 1984, OJ No. L67 of 9 March 1984.

European Economic Community. The European Consumer Electronics Industry. Brussels: EEC, 1985.

European Economic Community. "Multi-annual Research Action Programme for the European Economic Community in the Field of Biotechnology (1985-1989)." Council Decision of 12 March 1985, OJ No. L83 of 25 March 1985.

European Economic Community. "R&D Programme 1985-1988 in the Fields of Basic Technological Research and the Applications of New Technologies (BRITE)." Council Decision EEC/85/196 of 12 March 1985, OJ No. L83 of 25 March 1985.

European Economic Community. University-Industry Cooperation in Training: The "Comett" Programme. Brussels: EEC, July 1985.

European Economic Community. The Technology Community Begins to Take Shape "Towards European Technology Community". Brussels: EEC, September 1985, p. 70.

European Economic Community. Assessment of the Results of Community Research and Development. Brussels: EEC, March 1986.

European Economic Community. Commission Sees New Forward Looking Role for the Joint Research Centre in Future Commodity R&D Strategy. Brussels: EEC, March 1986.

European Economic Community. The Second Phase of ESPRIT - Tripling the European Response to American and Japanese Competition. Brussels: EEC, May 1986.

European Economic Community. Links with EUREKA and Evaluation of RTD Programmes: Two Important Horizontal Aspects of the European Technology Community. Brussels: EEC, November 1986.

European Economic Community. ESPRIT: Tangible Results with Significant Industrial Impact are Beginning to Emerge. Brussels: EEC, December 1986.

Eurostat. "Public Expenditures on Research and Development, 1975-1982." Statistical Office of the European Communities, Brussels, 1984.

Fabian, Yvan. "The OECD International S and T Indicators System." Science and Public Policy 11, 1 February 1984): 4-6.

Fallows, James. "Containing Japan." Atlantic Monthly (May 1989).

Farnoux, Abel. "Mission Filiere Electronique." Rapport de Synthese, Ministere de la recherche et de la technologie, January 1983.

Fawcett, Clifford W. "Factors and Issues in the Survival and Growth of the U.S. Machine Tool Industry." PhD. Dissertation, School of Business Administration, George Washington University, 1976.

Feeder, Barnaby J. "A Toolmaker's Survival Strategy." The New York Times (19 April 1988): D1-D2.

Fetherston, Martin, Barry Moore and John Rhodes. "EEC Membership and U.K. Trade in Manufactures." Cambridge J. of Econommics (December 1979): 339-407.

Fifield, Richard J., Series Editor. European Research Index. Guernsey, British Isles: Francis Hodgson, 1974.

Fifield, Richard J., Series Editor. Guide to Science and Technology in the UK. Guernsey, British Isles: Francis Hodgson, 1974.

Fifield, Richard J., Series Editor. Japan Research Index. Guernsey, British Isles: Francis Hodgson, 1974.

Finan, William F. "The International Transfer of Semiconductor Technology Through U.S.-Based Firms." NBER Working Paper No. 118. Washington DC: National Bureau of Economic Research, Inc., December 1975.

Finan, W.F. "The Semiconductor Industry's Record on Productivity." American Prosperity and Productivity: Three Essays on the Semiconductor Industry. Cupertino, CA: Semiconductory Industry Association, 1981.

Finan, W.F. "The Exchange of Semiconductor Technology Between Japan and the United States." First U.S.-Japan Technological Exchange Symposium. Washington, DC, 21 October 1981.

Fishlook, D. "Why Europe Wants ESPRIT." Financial Times (3 August 1982).

Flaherty, M.T. "Field Research on the Link Between Technological Innovation and Growth: Evidence from the Semiconductor Industry." American Economic Review, Papers and Proceedings 74 (1984): 67-72.

Floud, R. The British Machine Tool Industry 1850-1914. London: CUP, 1976.

Ford, Glyn, Ken Green, Fred Steward and Salma Ahmad. "Co-ordinating Strategic Research in Britain." Science and Public Policy 13, 5 (October 1986): 269-274.

Forstner, H. "The Changing Pattern of International Trade in Manufacturers: A Logit Analysis." Welwirtschaft. Arch. 120. 1 (1984): 1-17.

Francis, Arthur. New Technology at Work. New York: Clarendon (Oxford University Press), 1986.

Francis Kinsman and Associates. "The Impact of Microprocessors on British Business." National Computing Centre, 1979.

Franzmeyer, Fritz. Industrielle Strukturprobleme und sektorale Strukturpolitik in der Europäischen Gemeinschaft. Deutsches Institut für Wirtschaftsforschung, Berlin: Duncker & Humblot, 1979, pp. 151-158, Sonderheft 130.

Friedman, Abraham S. "Science and Technology in France." Physics Today 36, 6 (June 1983): 24-28.

Freedman, Ron. "The Science Policy Foundation (1964-1984)." Science and Public Policy (June 1984): 161-172.

Freeman, C. "The Role of Small Firms in Innovation in the United Kingdom since 1945." Committee of Inquiry on Small Firms, Research Report No. 6, London, 1971.

Freeman, Christopher. Technology Policy and Economic Performance. London: Printer Publishers, 1988.

Freeman, C., J. Clark and L. Soete. Unemployment and Technical Innovation: A Study of Long Waves and Economic Development. London, Frances Pinter, 1982.

Freeman, R. "A Model of International Competition in Research and Development." Presented at the Econometric Society Meetings, New York, December 1982.

Fuji Corporation. Japan Science & Technology Outlook. Fuji Corporation, 1983.

Gehrels, Franz. "Foreign Investment and Technology Transfer: Optimal Policies." Weltwirtsch. Arch. 119, 4 (1983): 663-685.

Geimer, R. and H. Geimer. Science in the Federal Republic of Germany: Organization and Promotion, Fourth Edition. Bonn: Deutscher Akademischer Austauschdienst, 1978.

Gellman Research Associates (S. Feinman and W. Fuentevilla). Indicators of International Trends in Technological Innovation. Report to the National Science Foundation. Washington, DC: National Technical Information Service, 1976.

German, Clifford F. "A Tentative Evaluation of World Power." Journal of Conflict Resolution 4 (1960).

Gerschenkron, Alexander. Economic Backwardness in Historical Perspective. Cambridge, Mass.: Harvard University Press, 1962.

Gerstenfeld, Arthur, ed. Science Policy Perspectives: USA-Japan. New York: Academic Press, 1982.

Gertouzos, R., et al. Made in America: Regaining the Production Edge. Cambridge, Mass.: MIT Press, 1989.

Gerybadze, A. and K.P. Friebe, eds. Microelectronics in Western Europe: Medium Term Perspective, 1983-87. Berlin, Eric Smidt-Verlag, 1983.

Gibbons, Michael and P.J. Gummett. "Government Policy and Innovation in England." In Technological Innovation Government/Industry Cooperation. Edited by Arthur Gerstenfeld. New York: John Wiley & Sons, 1979.

Gibbons, M., et al., eds. Science and Technology Policy in the 1980s and Beyond. London: Longman, 1984.

Gilpin, Robert G. France in the Age of the Scientific State. Center of International Studies Series. Princeton, NJ: Princeton University Press, 1968.

Goldberg, L. "The Influence of Federal R&D Funding on the Demands for Returns to Industrial R&D." Report No. CRC388, Public Research Institute Center for Naval Analysis, Alexandria, VA, October 1979.

Golden, William T., ed. Science and Technology Advice to the President and Judiciary. New York, Pergamon Press, 1988.

Golding, Anthony M. "Semiconductory Industry in Britain and the United States: A Case Study in Innovation, Growth and the Diffusion of Technology." PhD. Dissertation, University of Sussex, England, 1971.

Goldsmith, Maurice, ed. UK Science Policy: A Critical Review of R&D Policies. Harlow, UK: Longman, 1984.

Gort, M. and R.A. Wall. "The Evolution of Technologies and Investment in Innovation." Econ. J. 96, 383 (September 1986): 741-757.

Gray, H. Peter. "The Theory of International Trade Among Industrial Nations." Weltwirtsch. Arch. 116, 3 (1980): 447-470.

Green, Robert T. and James M. Lutz. "U.S. High Technology Import/Export Performance in Three Industries." J. Int. Bus. Stud. 11, 2 (Fall 1980): 112-117.

Gregor, Peter. Investment in Japan. Washington, DC: NAS Press, 1988.

Gremmen, H.J. and A.H.J. Vollenbergh. "An Input Approach to European Comparative Advantage in Advanced Products: A Study with Special Emphasis on the Netherlands." Weltwirtsch. Arch. 112, 2 (1986): 270-280.

Griliches, Zvi and Jacques Mairesse. "Comparing Productivity Growth: An Exploration of French and U.S. Industrial and Firm Data." Europ. Econ. Rev. 21, 1/2 (March/April 1983): 89-119.

Griliches, Zvi and F. Lichtenberg. "R&D and Productivity Growth at the Industry Level: Is There Still a Relationship?" In R&D Patents, and Productivity. Edited by Z. Griliches. Chicago University, Chicago Press, 1984.

Griliches, Zvi and F. Lichtenberg. "Interindustry Technology Flows and Productivity Growth: A Re-examination." Rev. Econ. Statist. 66, 2 (May 1984): 324-329.

Grossman, Gene M. and J. David Richardson. "Strategic Trade Policy: A Survey of Issues and Early Analysis." NBER Research Progress Report, 1984.

Gruber, William, Dileep Mehta and Raymond Vernon. "The R&D Factor in International Trade and International Investment of United States Industries." J. of Political Economy (February 1967): 20-37.

Gruber, William H. and Raymond Vernon. "The Technology Factor in a World Trade Matrix." In The Technology Factor in International Trade: A Conference of the Universities -- National Bureau Committee for Economic Research. Edited by R. Vernon. New York: NBER/Columbia University Press, 1970, pp. 233-272.

Gruber, W.H. and R. Vernon, eds. Technology Factor in International Trade. New York: Columbia Press, 1970.

Guile, Bruce R. and Harvey Brooks, eds. Technology and Global Industry, Companies and Nations in the World Economy. Washington, DC: National Academy Press, 1987.

Grunwald, Joseph and Kenneth Flamm. "The Global Factory: Foreign Assembly in International Trade." Washington, DC, 1985.

Gummett, Philip. Scientists in Whitehall. Manchester: Manchester University Press, 1980.

Gutmanis, I. The Effects of International Transfer of Semi-Conductor Technology. Prepared for the Department of Labor, 1978.

Gutmanis, I. The International Competitiveness of the U.S. Semi-Conductor Industry. Prepared for the Electronic Industries Association of Japan, 1981.

Gutmanis, I. "The Economic Impacts of Intel Corporation's Investment in Off-Shore Semiconductor Manufacturing Facilities." Prepared by Sterling Hobe Corporation for the Overseas Private Investment Corporation, 1980.

Gutmanis, I. "Prediction Model for Changes in Demand for Scientific and Technical Manpower Induced by Changes in Technology." Prepared under research grant from the National Science Foundation, 1981.

Gutmanis, I. "Models for Manpower Demand in Electronic Industry." Prepared for the Office of the Undersecretary of Defense Research and Engineering, Department of Defense, 1981.

Gutmanis, I. "Technology Transfer and Future Prospects for the Machine Tools Industry: The United States, Japan and Selected European Nations." Prepared for Tanaka, Walders & Ritger, Attorneys at Law, April, 1985.

Gutmanis, I. "Current Status of and Future Prospects for the Semiconductor Industry: The United States, Japan and Selected European Nations." Prepared for the Electronics Industries Association of Japan, 1986.

Habakkuk, N.J. American and British Technology in the Nineteenth Century: The Search for Labor-Saving Devices. Cambridge: Cambridge University Press, 1962.

Haberler, G. Survey of International Trade Theory, 2nd Edition. Princeton, 1961.

Hager, W. and R. Taylor. "The Geography of Protectionism: The Community's Investments and Options." In EEC Protectionism: Present Practices and Future Trends, Vol. 2. Brussels: European Research Associates, 1982.

Harding, William. "Semiconductor Manufacturing IBM, 1957 to the Present: A Perspective." IBM J. of Research and Development 25 (September 1981).

Hart, P.E. and E. Morgan. "Market Structure and Economic Performance in the United Kingdom." J. Industrial Economics XXV, 3 (March 1977): 177-193.

Hartely, M.G. and Anne Buckley, eds. The Challenge of Microprocessors. Manchester University Press, 1979.

Harvey, Anthony P. and Ann Pernet, eds. European Sources of Scientific and Technical Information, (5th ed.). London: Longman Group, 1981.

Haslam, Jonathan. "An Appraisal of Microelectronic Technology." National Westminster Bank Quarterly Review (May 1979): 55-64.

Hatsopoulos, George, et al. "U.S. Competitiveness Beyond Trade Deficit." Science 251 (15 July 1988): 299-307.

Hatzichronoglou, Thomas. "International Trade in High Technology Products: Europe's Competitive Position." In A European Future in High Technology. Edited by Henry Ergas. Centre for European Policy Studies, Brussels, 1986.

Hatzichronoglou, T. "Technological Indicators and the Measurement of Performance in International Trade, Part B: Data and Empirical Tests." Paper presented to the Workshop on Technological Indicators and the Measurement of International Trade Performance, Organization for Economic Cooperation and Development, Paris, 12-14 September 1983.

Hauff, Volker and Hans-Hilger Haunschild, eds. Forschung in der Bundesrepublik Deutschland, Second Edition. Stuttgart/Berlin Cologne/Mainz: Kohlhammer, 1976.

Haug, P. "U.S. High Technology Multinationals and Silicon Glen." Reg. Stud. 20, 2 (April 1986): 103-116.

- Haug, P., N. Hood and S. Young. "R&D Intensity in the Affiliates of U.S. Owned Electronics Companies Manufacturing in Scotland." Req. Studies 17 (1983): 383-392.
- Hauger, J. Scott and John F. Starns. "A Study of the Effect of Foreign Dependency: An Action Plan for Reducing Foreign Dependency." Prepared for Air Force Logistics Command, Wright-Patterson AFB, OH, contract No. F33600-85-C-0293, TASC, 15 March 1986.
- Hawkins, Robert G., ed. The Economic Effects of Multinational Corporations. Research in International Business and Finance, Volume I. Greenwich, Conn.: JAI Press, 1979.
- Heckscher, Eli F. Mercantilism. London: Pragg Publisher, 1919.
- Hector, Gary. "The U.S. Chipmakers Shaky Comeback." Fortune (20 June 1988).
- Hector, R.P. "Research Trends and Applications." Information Researcher Inc., Tokyo, Japan, 1987.
- Helpman, Elhanan. "International Trade in the Presence of Product Differentiation, Economies of Scale and Monopolistic Competition: A Chamberlin-Heckscher-Ohlin Approach." J. Internat. Econ. 11 (August 1981): 305-340.
- Helpman, Elhanan and Paul R. Krugman. Market Structure and Foreign Trade; Increasing Returns, Imperfect Competition, and the International Economy. Cambridge: MIT Press, 1985.
- Hewitt, Gary. "Research and Development Performed Abroad by U.S. Manufacturing Multinationals." Kyklos 33, 2 (1980): 308-327.
- Hibbard, W.R., ed. Substituting Non-Metallic Materials for Vulnerable Minerals. Materials and Society, 8, 2 (1984). New York: Pergamon Press, 27-28 June 1983.
- Hicks, J.R. Value and Capital: An Inquiry into Some Fundamental Principles of Economic Theory. London: Oxford Univ. Press, 1953.
- Hieronimi, Otto, ed. The New Economic Nationalism. Praeger Special Studies - Praeger Scientific. New York: Praeger, 1980.
- Hilts, Philip J. "Will Bush Pay Attention to Science?" The Washington Post (28 November 1988).
- Hirsch, S. Locations of Industry and International Competitiveness. Oxford, 1967.
- Hochstrasser, U. "Development of a European Science Policy." Science and Public Policy 13, 5 (October 1986): 265-268.

Hollander, A. "Foreign Location Decisions by U.S. Transnational Firms: An Empirical Study." Managerial Dec. Econ. 5, 1 (March 1984): 7-18.

Hood, N. and S. Young. European Development Strategies of U.S. Owned Manufacturing Companies Located in Scotland. Edinburgh: HMSO, 1980.

Horiba, Y. "General Equilibrium and the Heckscher-Ohlin Theory of Trade: The Multi-Country Case." International Economic Review 15 (1974): 440-449.

Horn, E.J., H. Klodt and C. Saunders. "Advanced Machine Tools: Production, Diffusion and Trade." E.C. Working Paper, Stuttgart, 1986.

Horstmann, Ignatius and James R. Markusen. "Strategic Investments, Firm Specific Capital, and the Development of Multinationals." University of Western Ontario working paper, 1983.

Hufbauer, Gary C. Synthetic Materials and the Theory of International Trade. London: G. Duckworth and Company, 1966.

Hufbauer, Gary C. "The Impact of National Characteristics and Technology on the Commodity Composition of Trade in Manufactured Goods." In The Technology Factor in International Trade. Edited by R. Vernon. New York: Columbia University Press for the National Bureau of Economic Research, 1970.

Hughes, A. and M.S. Kumar. "Aggregate Concentration in the U.K. Economy 1968-1980." Study prepared for the Office of Fair Trading, U.K., 1981.

Hutton, S.P., P.A. Lawrence and J.H. Smith. "The Recruitment, Deployment and Status of the Mechanical Engineer in the German Federal Republic." University of Southampton, p. 121, 1977. (Mimeographed.)

Inose, Hiroshi. "Government Policy and Innovation Policy in Japan." In Technological Innovation Government/ Industry Cooperation. Edited by Arthur Gerstenfeld. New York: Wiley-Interscience, 1979.

Integrated Circuit Engineering. Status 1980: A Report on the Integrated Circuit Industry. Scottsdale, AZ: ICE, 1981.

Integrated Circuit Engineering Corp., Status 1987: A Report on the Integrated Circuit Industry. Scottsdale, AZ, 1988.

International Trade Administration. "An Assessment of U.S. Competitiveness in High Technology Industries." U.S. Department of Commerce, February 1983.

International Trade Commission. "Foreign Industrial Targeting and its Effects on U.S. Industries, Phase I: Japan." 1983.

International Trade Commission. "Foreign Industrial Targeting and its Effects on U.S. Industries, Phase II: The European Community and Member States." 1984.

Japan External Trade Organization. "The Development of Structural Fine Ceramics in Japan." Japan Industrial and Technological Bull. Special Issue 15, Tokyo (1983).

Japan Information Processing Development Center. Computer White Paper: 1981 Edition. Tokyo, 1982.

Japan Information Processing Development Center. Outline of Research and Development Plans for Fifth Generation Computer Systems. Tokyo: Institute for New Generation Computer Technology, May 1982.

Japan Ministry of International Trade and Industry. "White Paper on International Trade - 1980." Tokyo, September 1980.

Japan Ministry of International Trade and Industry, Fine Ceramics Office. "Administrative Countermeasures for the Fine Ceramics Industry in Japan." Annual Report for Overseas Readers, 1986.

Japan Report, Joint Publications Research Service. "MITI Project to Develop Supercomputer Starts in January." JPRS L/10348, 23 February 1982.

Japan Society for the Promotion of Science. "Annual Report." Annual Series.

Japanese Science and Technology Agency. "Indicators of Science and Technology." Annual Series.

Johnson, Chalmers. MITI and the Japanese Miracle. Boston: Harvard University Press, 1982.

Johnson, H.G. "Economic Expansion and International Trade." Manchester School (May 1955).

Johnson, H.G. "Factor Endowments, International Trade and Factor Prices." Manchester School (September 1957).

Johnson, L.R., A.P.S. Teotia and L.G. Hill. "A Structural Ceramics Research Program: A Preliminary Economic Analysis." ANL/CNSV-38, Argonne National Laboratory, March 1983.

Joint Publications Research Service. "First Details Published on Electronics Plan." West Europe Report, Science and Technology No. 120. JPRS 8/804, 20 September 1982.

Jones, Norman. "Can American Compete." Business Week (20 April 1987).

Jorgenson, Dale, et al. Productivity and U.S. Economic Growth. Boston: University Press, 1988.

Junne, Gerd and Rob van Tulder. "European Multinationals in the Robot Industry, A Pilot Study." Universiteit van Amsterdam, 1984. (Mimeographed.)

Kahn, A.E. Great Britain in the World Economy. New York: Columbia University Press, 1946.

Kaldor, Nicholas. "A Model of Economic Growth." Economic Journal, LXVII (December 1957): 591-624.

Kaldor, Nicholas. "Further Essays on Economic Theory." Collected Economic Essays Volume 6. New York: Holmes and Meier, 1978, pp. 138-153.

Kaplinsky, Raphael. Computer-Aided Design: Electronics, Comparative Advantage and Development. London: Frances Pinter, 1982.

Katz, J.M. "Domestic Technological Innovations and Dynamic Comparative Advantage: Further Reflections on a Comparative Case-Study Program." J. Devel. Econ. 16, 1-2 (September-October 1984): 13-37.

Kay, Neil M. "Multinational Enterprises: A Review Article." Scottish J. of Political Economy 30, 3 (1983): 304-312.

Kealy, Terence. "How the EEC Ruins Research." The Spectator (18 April 1987).

Kennedy, P. "The (Relative) Decline of America." The Atlantic Monthly (August 1987).

Kennedy, W.P. "Economic Growth and Structural Change in the United Kingdom, 1870-1914" J. of Economic History 42 (1982): 105-114.

Kenney, G.B. and H.K. Bowen "High-Technology Ceramics in Japan: Current and Future Markets." Am. Ceram. Soc. Bull. 62, 5 (1983): 590-596.

Keyworth II, George A. "US Science Policy." Science and Public Policy (February 1982): 2-5.

Keyworth II, George A. "Federal R&D and Industrial Policy." Science 220 (10 June 1983).

Keyworth II, George A. "Four Years of Reagan Science Policy: Notable Shifts in Priorities." Science 224 (6 April 1984): 9-13.

Khalilzadeh-Shirazi, J. "Market Structure and Price-Cost Margins in United Kingdom Manufacturing Industries." Review of Economics and Statistics 56 (February 1974): 67-76.

Kikuchi, Makoto. Japanese Electronics, A Worm's Eye View of Its Evolution. Simul Press, 1983.

Kilby, Jack S. "Invention of the Integrated Circuit." IEEE Transactions on Electron Devices (July 1976).

Kindleberger, Charles P. Economic Growth in France and Britain, 1851-1950. Cambridge, MA: Harvard University Press, 1964.

Kinnock, Neil. "Putting Science to Work: A Strategy for the Future." Science and Public Policy 12, 6 (December 1985): 299-307.

Kleiman, Herbert S. "The Integrated Circuit: A Case Study of Product Innovation in the Electronics University." PhD. dissertation, The George Washington University, 1966.

Klein, Lawrence R. "Components of Competitiveness." Science 241 (15 July 1988): 308-313.

Kocka. "The Rise of the Modern Industrial Enterprise in Germany." In Managerial Hierarchies: Comparative Perspectives on the Rise of the Modern Industrial Enterprise. Edited by A.D. Chandler, Jr. and H. Daems. Cambridge, MA: Harvard University Press, 1980.

Kodama, Fumio. "Japanese Innovations in Mechatronics Technology." Science and Public Policy 13, 1 (February 1986).

Kohli, Ulrich R. "Technology and the Demand for Imports." Southern Econ. J. 50, 1 (July 1983): 137-150.

Kreile, M. "West Germany: The Dynamics of Expansion." In Between Power and Plenty: Foreign Economic Policies of Advanced Industrial States. Edited by P.J. Katzenstein. Madison, WI: University of Wisconsin Press, 1978.

Kronz, Hermann. "Patent Statistics at the Commission of the European Communities." Science and Public Policy 11, 1 (February 1984): 18-20.

Krugman, Paul. "Increasing Returns, Monopolistic Competition and International Trade." Journal of International Economics 9 (1979): pp. 395-410.

Krugman, Paul R. "Model of Innovation, Technology Transfer and the World Distribution of Income." J. Polit. Econ. 87, 2 (April 1979): 253-266.

Krugman, Paul. "Intraindustry Specialization and the Gains from Trade." J. Political Economy 89 (October 1981): 959-973.

Krugman, Paul R. "Targeted Industrial Policies: Theory and Evidence." Industrial Change and Public Policy: A Symposium. Federal Reserve Bank of Kansas City, MO, 1983, pp. 123-155.

Krugman, Paul R. "New Theories of Trade Among Industrial Countries." Amer. Econ. Rev. 73, 2 (May 1983): 343-347.

Krugman, Paul R. "The U.S. Response to Foreign Industrial Targeting: Comments." Brookings Pap. Econ. Act. 1 (1984): 125-129.

Krugman, Paul R. "Targeted Industrial Policies: Theory and Evidence." In Industrial Change and Public Policy. Symposium sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, WY, pp. 123-156, 1983.

Krugman, Paul R. "Import Protection as Export Promotion." In Monopolistic Competition International Trade. Edited by H. Kierzkowski. Oxford: Oxford University Press, 1984.

Krugman, Paul. "The U.S. Response to Foreign Industrial Targeting." Brookings Papers on Economic Activity. Washington, DC: Brookings Institution, 1984.

Kuhn, Thomas and Alan L. Porter. Science, Technology and National Policy. Ithaca, NY: Cornell University Press, 1980.

Kumar, M.S. "Comparative Analysis of U.K. Domestic and International Firms." J. Econ. Stud. 11, 3 (1984): 26-42.

Kumar, M.S. "International Trade and Industrial Concentration." Oxford Econ. Pap. 37, 1 (March 1985): 125-133.

Lahr, Steve. "A Case Study of Thatcherism." The New York Times. (5 December 1988).

Lancaster, K. "The Heckscher-Ohlin Trade Model: A Geometric Treatment." Economica (February 1957).

Landau, Ralph. "U.S. Economic Growth." Scientific American 258, 6 (1988): 44-52.

Landau, Ralph and Nathan Rosenberg, eds. The Positive Sum Strategy: Harnessing Technology for Economic Growth. Washington, DC: National Academy Press, 1986.

Landau, Ralph and Dale Jorgenson, eds. Technology and Economic Policy. New York: Ballinger Publishing Company, 1986.

Larsen, F., J. Llewellyn and S. Potter. "International Economic Linkages." OECD Econ. Stud. 1 (Autumn 1983): 43-91.

Lazonick, William. "The Social Determinants of Technological Innovation." Presented at the Conference on Technology and the Enterprise in an Historical Perspective, Terni, Italy, October 1987.

Leamer, Edward E. Sources of International Comparative Advantage: Theory and Evidence. Cambridge: MIT Press, 1984.

Leamer, Edward E. and Harry P. Bowen. "Cross-Section Tests of the Heckscher-Ohlin Theorem: Comment." American Economic Review 71 (December 1981): 1040-1043.

Lederman, L.L. "Science and Technology Policies and Priorities: A Comparative Analysis." Science 237 (4 September 1987).

Lederman, Leonard L. "Science and Technology in Europe: A Survey." Science and Public Policy 12, 3 (June 1985): 131-143.

Lederman, Leonard L., Rolf Lehming and Jennifer Bond. "Research Policies and Strategies in Six Countries: A Comparative Analysis." Science and Public Policy 13, 2, (April 1986): 67-76.

Lehman, J. and T.D. Willett. "National Security and Industrial Policy: The Need for a Public Choice Perspective." Contemp. Policy Issue 4, 1 (January 1986): 36-47.

Lenoe, E.M. and J.L. Meglen. "International Perspective on Ceramic Heat Engines." Ceramic Bulletin 64, 2 (1985).

Leonard, H. Jeffrey and Robert Gilpin. "Industrial and Technological Policies of Western Economies." In Technology and International Affairs. Edited by Joseph S. Szyliowicz. New York: Praeger, 1981, p. 132.

Leontif, W.W. "Factor Proportions and the Structure of American Trade: Further Theoretical and Empirical Analysis." Review of Economics and Statistics 38 (1956).

Leontif, W.W. "International Factor Cost and Factor Use." American Economic Review (June 1964).

Leveson, Irving and Jimmy W. Wheeler, eds. Western Economies in Transition: Structural Change and Adjustment Policies in Industrial Countries. With the editorial assistance of Ernest Schneider, Hudson Institute Studies on the Prospects for Mankind. Boulder, CO: Westview Press; London: Croom Helm, 1980.

Levin, R.C. "Innovation in the Semiconductor Industry: Is a Slow-down Imminent?" In R&D Productivity. Edited by H.I. Fusfield. New York: Pergamon Press, 1983.

Levy, David M. and Nestor E. Terleckyj. "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis." Paper prepared for the Annual Meeting of the Southern Economic Association, Atlanta, GA, 11 November 1982.

Linder, S.B. An Essay on Trade and Transformation. Stockholm: Almqvist and Wiksell; New York: John Wiley & Sons, 1961.

Loertscher, Rudolf and Frank Wolter. "Determinants of Intra-Industry Trade: Among Countries and Across Industries." Weltwirtschaftliches Archiv. 116 (1980): 220-292.

Love, S. "New Talent Spurs Britain's ICL." Wall Street Journal (1 March 1982).

Lowe, J. "Science Parks in the U.K." Lloyds Bank Rev. 156 (1985): 31-42.

Lunn, John. "Determinants of U.S. Direct Investment in the EEC: Revisited Again." Europ. Econ. Rev. 21, 3 (May 1983): 391-393.

Lutz, James M. and Robert T. Green. "The Product Life Cycle and the Export Position of the United States." J. Int. Bus. Stud. 14, 3 (Winter 1983): 77-93.

MacDonald, Stuart, Donald McLean Lamberton and Thomas Mandeville, eds. The Trouble with Technology: Explorations in the Process of Technological Change. New York: St. Martin's Press, 1983.

Machida, Y. "Industrial Robot in Japan." LTCB Research, Long-Term Credit Bank of Japan (March/April 1981).

Macioti, Manfredo. "Progress of European Science and Technology." Science and Public Policy 13, 2 (April 1986): 97-100.

Mackintosh, Ian. Microelectronics in the 1980's. London: Mackintosh Publications, Ltd., 1979.

Macreary, S.E., ed. Guide to Science and Technology in the U.K. Accord, MA: International Publications, 1971.

Majumdar, Badiul Alam. "Innovations and International Trade: An Industry Study of Dynamic Competitive Advantage." Kyklos 32, 3 (1979): 559-570.

Malerba, Franco. "Demand structure and technological change; the case of the European semiconductor industry." Research Policy 14 (1985).

Mansfield, Edwin. "International Technology Transfer: Rates, Benefits, Costs, and Public Policy." Presented at the A.E.A. Meetings in Washington, DC, December 1981.

Mansfield, Edwin. "Long Waves and Technological Innovation." Amer. Econ. Rev. 73, 2 (May 1983): 141-145.

Mansfield, E. "How Rapidly Does New Industrial Technology Leak Out?" J. Ind. Econ. 34, 2 (December 1985): 217-223.

Mansfield, Edwin. "Industrial R&D in Japan and the United States: A Comparative Study." American Economic Review 78, 2 (May 1988): 33-49.

Mansfield, Edwin. "Industrial Innovation in Japan and the United States." Science (30 September 1988): 1769-1774.

Mansfield, Edwin and Anthony Romeo. "Technology Transfer to Overseas Subsidiaries by U.S.-Based Firms." Quart. J. Econ. 95, 4 (December 1980): 737-750.

Mansfield, E., A. Romeo, M. Schwartz, D. Teece, S. Wagner and P. Brach. Technology Transfer, Productivity, and Economic Policy. New York: W.W. Norton, 1982.

Manufacturing Studies Board. The U.S. Machine Tool Industry and the Defense Industrial Base. Washington, DC: National Academy Press, 1983.

Markoff, John. "The Chip War: The Battle for World Tomorrow." New York Times (14 May 1989).

Markusen, J.R. and L.E.O. Svensson. "Trade in Goods and Factors with International Differences in Technology." Int. Econ. Rev. 26, 1 (February 1985): 175-192.

Marshall, A. "The Pure Theory of Foreign Trade" and "The Pure Theory of (Domestic) Values." In London School of Economics Reprint of Scarce Tracts, No. 1, London, 1930.

Martin, B.R., J. Irvine and R.E. Turner. "The Writing on the Wall for British Science." New Scientist (November 1984).

Maskus, Keith E. "Evidence on Shifts in the Determinants of the Structure of U.S. Manufacturing Foreign Trade, 1958-76." Rev. Econ. Statist. 65, 3 (August 1983): 415-422.

Massow, Valentin von. Organisation and Promotion of Science in the Federal Republic of Germany. Bonn: Inter Nationes, 1983.

Matthews, R.C.O., C.H. Feinstein and J. Odling-Smee. British Economic Growth 1856-1973. Stanford: Stanford University Press, 1982.

Maxwell Stamp Associates. High Samuel Occasional Paper No. 4: The Role of the Government in Research and Development. London: Hill Samuel & Co., Ltd., October 1969.

McDermott, P. "Multinational Manufacturing Firms and Regional Development: External Control in the Scottish Electronics Industry." Scot. J. Pol. Econ. 26 (1979): 287-306.

McIntosh, J. "Economic Growth and Technical Change in Britain 1950-1978." Europ. Econ. Rev. 30, 1 (February 1986): 117-128.

Metcalf, J.S. and L. Soete. "Notes on the Evolution of Technology and International Competition." In Science and Technology Policy in the 1980's and Beyond. Edited by M. Gibbons, et al. Longman, 1984.

Ministry of Technology. "Report of the Working Party on the Problems Arising from the Cyclical Pattern of Machine Tool Orders." HMSO, London, 1966.

Mistral, J. "Filières et compétitivité: en jeux de politique industrielles." Annales des Mines. Les filières industrielles, January 1980.

Mitterrand, François. "Technology Employment and Growth." Report by the President of the French Republic, at the Summit of the Industrialized Countries, Chateau de Versailles, 1982.

Modigliano, F. and G. Balcer. "New Trends in Internationalization: Processes and Theories. Diversified Patterns of Multinational Enterprise and Old and New Forms of Foreign Involvement of the Firm." Econ. Notes 3 (1983): 42-68.

Moritami, M. Advanced Technology and Japanese Contribution. Tokyo: Nomura Securities Co., 1983.

Mowery, David. "Innovation, Market Structure, and Government Policy in the American Semiconductor Electronics Industry: A Survey." Research Policy 12 (1983).

Mowery, D. "Economic Theory and Government Technology Policy." Policy Sciences 16 (1983): 27-43.

Moxon, R.W. "Effects of Offshore and Onshore Foreign Direct Investment in Electronics: A Survey." Prepared for the Office for Technology Assessment, November 1983.

Muir, R. Modern Political Geography. London: Macmillan, 1975.

Mullins, Nicholas C. "Evaluating Research Programs: Measurement and Data Sources." Science and Public Policy 14, 2 (April 1987): 91-98.

Murphy, John W. "A Modern View on the Transfer of Technology." Science and Public Policy 12, 3 (June 1985): 144-148.

Narin, Francis and J.D. Frame. "The Growth of Japanese Science and Technology." Science 245 (11 August 1989).

National Academy of Engineering. "The Competitive Status of the U.S. Machine Tool Industry." Office of the Foreign Secretary, 1983.

National Academy of Engineering. Technology and Competitiveness. Washington, DC: NAE Press, 1988.

National Academy of Sciences. Applications of Robotics and Artificial Intelligence to Reduce Risk and Improve Effectiveness. Washington, DC: National Academy Press, 1983.

National Academy of Sciences. The Competitive Status of the U.S. Machine Tool Industry: A Study of the Influences of Technology in Determining International Industrial Competitive Advantage. Washington, DC: National Academy Press, 1983.

National Academy of Science. Frontiers of Science and Technology: A Selected Outlook. Committee on Science, Technology and Public Policy of the National Academy of Science, the National Academy of Engineering and the National Institute of Medicine. New York: N.A. Freeman, 1983.

National Academy of Science. The Future of Electronics Assembly. Washington, DC: National Academy Press, 1988.

National Machine Tool Builders Association. "The Economic Handbook of the Machine Tool Industry." McLean, VA, 1985.

National Materials Advisory Board. Basic and Strategic Metals Industries Threats and Opportunities. Report NMAB-425, Washington, DC: National Academy Press, 1985.

National Research Council. Technology, Trade, and the U.S. Economy. Office of the Foreign Secretary, National Academy of Engineering and Assembly of Engineering. Report of a Workshop held at Woods Hole, MA, 22-31 August 1976. Washington, DC: National Academy of Sciences, 1978.

National Research Council. The U.S. Machine Tool Industry and the Defense Industrial Base. Committee on the Machine Tool Industry. Washington, DC: National Academy Press, 1983.

National Research Council. Applications of Robotics and Artificial Intelligence to Reduce Risk and Improve Effectiveness. Commission on Engineering and Technical Systems, Committee on Army Robotics and Artificial Intelligence Manufacturing Studies Board. Washington, DC: National Academy Press, 1983.

National Research Council. The U.S. Machine Tool Industry and the Defense Industrial Base. Commission on Engineering and Technical Systems, Committee on the Machine Tool Industry Manufacturing Studies Board. Washington, DC: National Academy Press, 1983.

National Research Council. The Competitive Status of the U.S. Electronics Industry. Committee on Technology and International Economic and Trade Issues. Washington, DC: National Academy Press, 1984.

National Research Council. High Technology Ceramics in Japan. Commission on Engineering and Technical Systems, Committee on the Status of High Technology Ceramics in Japan, National Materials Advisory Board. Washington, DC: National Academy Press, 1984.

National Research Council. "An Assessment of the Impact of the Department of Defense Very-High Speed Integrated Circuit Program." National Materials Advisory Board Report NMAB-382, Washington, DC, 1986.

National Research Council. Ceramic Technology for Advanced Heat Engines. Committee on Ceramic Technology for Advanced Heat Engines, National Materials Advisory Board. Publication No. NMAB-431. Washington, DC: National Academy Press, 1987.

National Science Foundation. The 5-Year Outlook for Science and Technology 1981. Source Materials Volumes 1 and 2. Washington, DC: U.S. Government Printing Office, 1982.

NSF. "Emerging Issues in Science and Technology." NSF 82-27, Washington, DC, 1982.

NSF. "1990 R&D Funding Projections." NSF 82-315, Washington, DC, 1982.

NSF. "Federal Funds for Research and Development, Fiscal Years 1982, 1983, and 1984." (Serial Report), Vol. XXXII, NSF 83-139, Washington, DC, 1983.

NSF. "Federal R&D Funding by Budget Function, Fiscal Years 1983-85." NSF 84-316, Washington, DC, 1984.

NSF. "Science and Technology Resources 1984." (Serial Report), NSF 84-311, Washington, DC, 1984.

NSF. "Federal R&D Funding: The 1975-1985 Decade." Washington, DC, March 1984.

NSF. "Basic Research in Japan: Policy in Flux." Report Memorandum No. 52, Tokyo: U.S. National Science Foundation, 29 November 1984.

NSF, Division of Science Resources Studies. "Federal Funds for Research and Development: Detailed Historical Tables: Fiscal Years 1967-1987." Washington, DC, 1988.

Negandhi, Anat R., ed. Functioning of the Multinational Corporation: A Global Comparative Study. New York; Oxford; Toronto and Paris: Pergamon Press, 1980, pp. 117-135.

Nelson, Richard R. "Closer Integration of Science Policy and Economic Policy." In Technological Innovation Government/Industry Cooperation. Edited by Arthur Gerstenfeld. New York: John Wiley & Sons, pp. 196-205, 1979.

Nelson, Richard R., ed. Government and Technical Change. New York: Pergamon Press, 1982.

Nelson, Richard R. and S.G. Winter. "Towards a Useful Theory of Innovation." Research Policy 6 (1977).

Nelson, Richard R. and S.G. Winter. An Evolutionary Theory of Economic Growth. Cambridge, MA: The Belknap Press, Harvard University, 1982.

Neumann, M., I. Bobel and A. Haid. "Innovation and Market Structure in West Germany." Nurnberg, 1981. (Mimeographed.)

New York Times. "Sematech's Weary Hunt for a Chief." (1 April 1988).

Nielsen, R.P. "Government-Owned Businesses: Market Presence, Competitive Advantages and Rationales for Their Support by the State." American J. Economics and Sociology 41 (1982): 17.

Nordhaus, W. "Picking Winners: Who Wins?" Prepared for the National Academy of Science's Panel on Advanced Technology Competition and the Industrialized Allies, 9 February 1982.

Norman, C. "Unsavory Force in Science Exchanges." Science 237 (4 September 1987).

Norris, K. and J. Vaizey. The Economics of Research and Technology. London: George Allen & Unwin, 1973.

Northcott, J. and P. Rogers. Microelectronics in Industry: What's Happening in Britain. London: Policy Studies Institute, March 1982.

Northcott, J. and P. Rogers. Microelectronics in Industry: An International Comparison: Britain, Germany, France. London: Policy Studies Institute and the Anglo-German Foundation, 1985.

Noyce, Robert N. "Microelectronics." In The Microelectronics Revolution. Edited by Tom Forester. Cambridge, MA: MIT Press, 1981.

Noyce, Robert N. and M.E. Hoff, Jr. "A History of Microprocessor Development at Intel." IEEE MICRO (February 1981).

OECD. Reviews of National Science Policy: Japan. Paris: OECD, 1967.

OECD. Reviews of National Science Policy: United Kingdom and Germany. Paris: OECD, 1967.

OECD. Reviews of National Science Policy: United States. Paris: OECD, 1968.

OECD. The Research System: Vol. 1, France, Germany, United Kingdom. Paris: OECD, 1972.

OECD. The Industrial Policy of Japan. Paris: OECD, 1972.

OECD. Social Sciences Policy: France. Paris: OECD, 1975.

OECD. Economic Survey: Japan. Paris: OECD, 1979 and 1980.

OECD. Science and Technology Policy for the 1980's. Paris: OECD, 1981.

OECD. Science and Technology Indicators I: Trends in Science and Technology in the OECD Area During the 1970's. Paris: OECD, 1982.

OECD. Science and Technology Indicators, Volume A: The Objectives of Government R&D Funding, 1974-1985. Paris: OECD, May 1983.

OECD. Science and Technology Indicators, Volume B: Gross National Expenditures on R&D, 1963-79. Paris: OECD, May 1983.

OECD. Science and Technology Indicators, Volume C: Total R&D Personnel. Paris: OECD, May 1983.

OECD. Science and Technology Indicators, Volume D: R&D in the Business Enterprise Sector, 1963-79. Paris: OECD, May 1983.

OECD. Industrial Robots. Their Role in Manufacturing Industry. Paris: OECD, 1983.

OECD. "Robots: The Users and the Makers." The OECD Observer 123 (July 1983): 11-17.

OECD. Science and Technology Indicators, Recent Results: Selected Science & Technology Indicators, 1979-83. Paris: OECD, June 1984.

OECD. Science and Technology Indicators, Resources Devoted to R&D. Paris: OECD, 1984.

OECD. "Trade in High Technology Products." Background Report on the Method of Work and Findings of the Studies carried out by the Industry Committee and the Committee for Scientific and Technological Policy, DSTI/SPR/84.1, DSTI/IND/84.7. Paris, January 1984.

OECD. "Trade in High Technology Products. An Examination of Trade Related Issues in the Machine Tool Industry." DSTI/SPR/ 83.102, OSTI/IND/83.40 (2nd rev.), Paris, 22 March 1984.

OECD. Science and Technology Public Outlook. Paris: OECD, 1985.

O'Brien, P.K. and C. Keyder. Economic Growth in Britain and France, 1780-1914, London: Allen and Unwin, 1978.

Office for Official Publications of the European Communities. European Research Policy. Luxembourg, October 1985.

Office for Official Publications of the European Communities. Grants and Loans from the European Community, Third Edition. Luxembourg, 1985.

Office for Official Publications of the European Communities. An Industrial Strategy for Europe. Luxembourg, February 1986.

Office for Official Publications of the European Communities. Telecommunications and Europe's Future. Luxembourg, August/ September 1986.

Office for Official Publications of the European Communities. The Sprint Programme. Luxembourg, November 1986.

Office of Technology Assessment. U.S. Industrial Competitiveness: A Comparison of Steel, Electronics and Automobiles. OTA-ISC-135. Washington, DC: U.S. Congress,, July 1981.

Office of Technology Assessment. International Competitiveness in Electronics. Washington, DC: U.S.G.P.O., 1984.

Office of Technology Assessment. "Research Funding as an Investment: Can we Measure the Returns." Technical memorandum, April 1986.

Office of Technology Assessment. Educating Scientists and Engineers. Washington, DC: U.S.G.P.O., 1988.

Ohlin, B. "Reflections on Contemporary International Trade Theories." In Interregional and International Trade, 2nd Revised Edition. Cambridge, MA, 1967.

Oldham, William G. "The Fabrication of Microelectronic Circuits." In The Microelectronics Revolution. Edited by Tom Forester. Cambridge, MA: MIT Press, 1981.

Ozaki, R.S. The Control of Imports and Foreign Capital in Japan. New York: Praeger, 1972.

Ozawa, Terutoma. "Japan's Technological Challenge to the West, 1950-1974: Motivation and Accomplishment." The Massachusetts Inst. of Technology, 1974.

Pack, H. and L.E. Westphal. "Industrial Strategy and Technological Change: Theory Versus Reality." J. Devel. Econ. 22, 1 (June 1986): 87-128.

Palmer, Arthur. "Science, Industry and a British Parliamentary Committee." Science and Public Policy 14, 3 (June 1987).

Panic, M. and P.L. Joyce. "U.K. Manufacturing Industry: International Integration and Trade Performance." Bank of England Quarterly Bulletin 20 (1980): 42-55.

Pavitt, Keith. "Science and Technology Indicators: Eight Conclusions." Science and Public Policy 11, 1 (February 1984): 21-24.

Pavitt, Keith. "The Objectives of Technology Policy." Science and Public Policy 14, 4 (August 1987): 182-188.

Pavitt, Keith, ed. Technical Innovation and British Economic Performance. Science Policy Research Unit, Sussex, series. London: Macmillan Press, distributed in the U.S. by Humanities Press, Atlantic Highlands, NJ, 1980.

Pavitt, Keith and S. Wald. The Conditions for Success in Technological Innovation. Paris: OECD, 1971.

Peacock, A. "Structural Economic Policies in West Germany and the U.K.," Anglo-German Foundation for the Study of Industrial Society, London, 1980.

Perry, Robert. "Multinational Acquisition: An Overview Report." The Rand Corporation, Santa Monica, CA, July 1980.

Phillips, David. "A Strategy for Science in the UK." Science and Public Policy 15, 1 (February 1988).

Pickering, J.F. and I.M. Sheldon. "International Trade Performance and Concentration in British Industry." Appl. Econ. 16, 3 (June 1984): 421-442.

Piekarz, Rolf, Eleanor Thomas and Donna Jennings. "International Comparisons of Research and Development Expenditures." Paper presented at the American Enterprise Institute Conference, International Comparisons of Productivity and Causes of the Slowdown, September 30, 1982.

Posner, M.V. "International Trade and Technical Change." Oxford Economic Papers New Series (October 1961): 323-341.

Prais, S.J. The Evolution of Giant Firms in Britain. Cambridge: Cambridge University Press, 1976.

Prais, S.J. Productivity and Industrial Structure. A Statistical Study of Manufacturing Industry in Britain, Germany and the U.S. Cambridge: Cambridge University Press, 1981.

President's Commission on Industrial Competitiveness. Global Competition - The New Reality, Volumes I and II. Washington, DC: U.S. Government Printing Office, January 1985.

Prestowitz. Trading Places. Cambridge, MA: MIT Press, 1988.

Pugel, T.A. "Endogenous Technological Change and International Technology Transfer in a Ricardian Trade Model." J. of International Economics 13 (1982): 321-335.

Pugel, Thomas. "Changing Patterns in Production and R&D: The Semiconductor Industry." (Comparison of European, U.S. and Japanese Industries). New York University, 1982.

Pugel, Thomas A. "The United States." In Multinational Enterprises, Economic Structure and International Competitiveness. Edited by John H. Dunning. New York: Wile, 1985, pp. 57-90.

Puu, Tonu and Soren Wibe, eds. The Economics of Technological Progress. Proceedings of a Conference Held by the European Production Study Group in Umea, Sweden, 23-25 August 1978, including a Bibliography on the Subject. New York: St. Martin's Press, 1980.

Ratcliffe, B.M. Great Britain and her World, 1750-1914: Essays in Honour of W.O. Henderson. Manchester: Manchester University Press, 1975.

Ray, George F. The Diffusion of Mature Technologies. Cambridge: Cambridge University Press, 1984.

Reich, R.B. "High Technology, Defense and International Trade." In The Militarization of High Technology. Edited by J. Tirman. Cambridge: Ballinger Publishing Company, 1984.

Reingold, Nathan and Marc Rothenberg, eds. Scientific Colonialism, A Cross-Cultural Comparison. Washington, DC: Smithsonian Institution Press, 1987.

Rendeiro, Joao O. "Technical Change and Strategic Evolution in the Machine Tool Industry." Sussex European Research Centre 1984. (Mimeographed.)

Ricardo, D. An Essay on the Influence of a Low Price of Corn on the Profits of Stock. London: John Murray, 1815.

Richards, Evelyn. "Search for U.S. Strategy on Chips at Cross-roads." Washington Post (8 January 1989).

Richardson, David J. "International Trade Policies in a World of Industrial Change." In Industrial Change and Public Policy. Symposium sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, WY, 1983, pp. 267-312.

Richerson, D.W. "Evolution in the U.S. of Ceramic Technology for Turbine Engines." Ceramic Bulletin 64, 2 (1985).

Robinson, R. "Factor Proportions and Comparative Advantage." Quarterly J. of Economics (May 1956).

Rosenberg, N. "Technological Change in the Machine Tool Industry 1840-1910," J. of Economic History (1963).

Rosenberg, Nathan. "The International Transfer of Industrial Technology, Past and Present." In North-South Technology Transfer, The Adjustment Ahead. Paris: OECD, 1982, pp. 25-47.

Rosenberg, N. Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press, 1982.

Rosenberg, Nathan, "U.S. Economic Policy: Implications for R&D." In Industrial R&D and U.S. Technological Leadership. National Academy of Science. Washington, DC: National Academy Press, 1988.

Rosenberg, N. and C.R. Frischtak. "Technological Innovation and Long Waves." Cambridge J. Econ. 8, 1 (March 1984): 7-24.

Rostas, L. Comparative Productivity in British and American Industry. Cambridge: Cambridge University Press, 1948.

Rothwell, Roy. "Reindustrialization and Technology: Towards a National Policy Framework." Science and Public Policy 12, 3 (June 1985): 113-130.

Rothschild Report 1971. "The Organization and Management of Government Research and Development, CMND 8414. HMSO, 1971.

Rowen, Hobart. "The Verdict's Still Out on High-Tech Help." The Washington Post (24 September 1989).

Rubenstein, Arthur H., et al. "Management Perceptions of Government Incentives to Technological Innovation in England, France, West Germany and Japan." Research Policy 6 (1977): 324-357.

Rugman, Alan M. "Multinational Enterprises and World Product Mandates." In Multinationals and Technology Transfer. Edited by A.M. Rugman, 1983.

Rugman, A.M. "New Theories of the Multinational Enterprise: An Assessment of Internationalization Theory." Bull. Econ. Res. 38, 2 (May 1986): 101-118.

Saatz, Thomas L. and M.W. Khouja. "A Measure of World Influence." Journal of Peace Studies 2 (1976).

Sahal, D. Patterns of Technological Innovation. Reading: Addison-Wesley, 1981.

Sakikabara, E., R. Feldman and Y. Harada. "The Japanese Financial System im Comparative Perspective." U.S. Congress, Joint Economic Committee Report, March 1982.

Samuelson, P. "International Trade and the Equalisation of Factor Prices." Economic J. 59 (June 1949) 181-197.

Sanger, David E. "A High-Tech Lead in Danger." The New York Times (December 18, 1988).

Sanger, David E. "Japanese Electronics Trive Despite Asian Competition." The New York Times (28 December 1988).

Sanger, David E. "Mighty MITI Loses Its Grip." The New York Times (3 July 1989).

Saunders, Christopher Thomas. "Engineering in Britain, West Germany and France." Sussex European Papers No. 3. Brighton, University of Sussex, 1978.

Scherer, F.M. Industrial Market Structure and Economic Performance. 2nd Edition. Boston: Houston Mifflin, 1980.

Scherer, F.M. "Concentration, R&D, and Productivity Change." Southern Econ. J. 50, 1 (July 1983): 221-225.

Schott, K. Industrial Innovation in the United Kingdom, Canada and the United States. London: Contemprint, July 1981.

Schumpeter, Joseph A. History of Economic Analysis. London: Oxford University Press, 1934.

Schumpeter, J.A. Capitalism, Socialism and Democracy. London: Allen and Unwin, 1943.

Schwarz, Michiel. "European Policies on Space Science and Technology: 1960-1978." Research Policy 8 (1979): 204-243.

Scibberas, E., et al. Competition, Technical Change and Manpower in Electronic Capital Equipment: A Study of the U.K. Mini-Computer Industry. Brighton: Science Policy Research Unit, 1978.

Science and Engineering Research Council. "Report of the Council for the Year." Science and Engineering Research Council, London, annual.

Science and Technology Agency. "White Paper on Science and Technology, 1982." Foreign Press Center, Japan, April 1984.

The Scientific and Technical Research Committee (CREST) - Its Origin, Role and Function. Commission, Luxembourg, 1975.

Scottish Development Agency. The Electronics Industry in Scotland. Glasgow: Booz, Allen and Hamilton, 1979.

Scottish Development Agency. Electronics Companies in Scotland. Glasgow: SDA, 1981.

Secretary of State for Prices and Consumer Protection. A Review of Monopolies and Merger Policy. Cmd 7198. London: HMSO, 1978.

Seers, Dudley and Constantine Vaitsos, eds. Integration and Unequal Development: The Experience of the EEC. Studies in the Integration of Western Europe. Assisted by Marja-Liisa Kiljunen. New York: St. Martin's Press, 1980.

Semiconductor Industry Association. The International Microelectronic Challenge. Cupertino, CA:SAI, May 1981.

Semiconductor Industry Association. The Effect of Government Targeting on the World Semiconductor Competition: A Case History of Japanese Industrial Strategy and its Costs for America. Cupertino, CA: SAI, 1983.

Semiconductor Industry Association. Effects of Foreign Industrial Targeting on World Semiconductor Competition. Cupertino, CA: SAI 1983.

Semiconductor Industry Association. SIA Trade Statistics. Cupertino, CA: Semiconductor Industry Association, annual.

Sharp, M., et al. Managing Change in British Industry. ILO, Vincent House, London 1988.

Shepherd, Geoffrey, Francois Duchene and Christopher Saunders, eds. Europe's Industries: Public and Private Strategies for Change. Cornell Studies in Political Economy. Ithaca, NY: Cornell University Press, 1983.

Shimo, Kotaro. "Imported Technology, Originality and Exports from Japan." Science and Public Policy 13, 1 (February 1986): 3-6.

Shinohara, Miyoei. Industrial Growth, Trade, and Dynamic Patterns in the Japanese Economy. Tokyo: University of Tokyo Press, 1982.

Silin, R.H. The Japanese Semiconductor Industry: An Overview. Hong Kong: Bank of American Asia Ltd., January 1979.

Skolnikoff, Eugene. "Impact of Science and Technology on the International System." In Global Technological Change: A Strategic Assessment. Proceedings of a Symposium for Senior Executives, Industrial Liaison Program, MIT, 21-23 June 1983.

Smith, D.M. Industrial Location: An Economic Geographical Analysis. New York: Wiley, 1981.

Smith, J. "Can Europe Cooperate on Research?" Electronics (25 August 1982).

Soete, L. "Innovation and International Trade." In Knowns and Unknowns in Technical Change. Edited by B.R. Williams and J.A. Bryan-Brown. London: Technical Change Centre, 1985.

Soete, L. and P. Patel. "Recherche-developpement importations de technologie et croissance Economique: Une tentative de comparaison internationale" ("R-D, International Technology Imports and Economic Growth: An International Comparison" with English summary). Revue Econ. 36, 5 (September 1985): 975-1000.

Solo, Robert A. "Industrial Policy." J. Econ. Issues 18, 3 (September 1984): 697-714.

Spence, A.M. "Industrial Organization and Competitive Advantage in Multinational Industries." Amer. Econ. Rev. 74, 2 (May 1984): 356-360.

Spencer, Barbara J. and James A. Brander. "International R&D Rivalry and Industrial Strategy." Rev. Econ. Stud. 50, 4 (October 1983): 707-722.

Steele, Lowell W. and N. Bruce Hannay. The Competitive Status of the U.S. Industry - An Overview. National Research Council. Washington, DC: National Academy Press, 1985.

Sterling Hobe Corporation. "Impact of Technology Transfer on the U.S. Semiconductor Industry." Prepared for the U.S. Department of Labor, 1979.

Sterling Hobe Corporation. "The Present State of and Prospects for the Domestic Semiconductor Industry." Prepared for Tanaka, Walders and Ritger, Attorneys at Law, 1979.

Sterling Hobe Corporation. "Supply and Demand of Scientific and Technical Manpower in the United States Electronic Industries." Prepared for the Office of Technology Assessment, U.S. Congress, 1980.

Sterling Hobe Corporation. "Analysis of Economic Performance for Selected Sectors of the U.S. Economy." Prepared for the Office of the United States Trade Representative, Executive Office of the President, 1981.

Sterling Hobe Corporation. "An Analysis of the Impact of a Proposed LDC Semiconductor Project on the U.S. Economy." Prepared for the Overseas Private Investment Corporation, 1982.

Sterling Hobe Corporation. "Analysis of Scientific and Technical Personnel Supply and Demand in the Semiconductor Industry." Prepared for the U.S. Department of Defense, 1982.

Sterling Hobe Corporation. "Analysis of Selected Issues on International Trade in Semiconductors." Prepared for Wald, Harkrader & Ross, 1984.

Sterling Hobe Corporation. "An Analysis of the U.S. Microelectronics Industry: Overseas Operations." Prepared for the Overseas Private Investment Corporation, 1986.

Sterling Hobe Corporation. "Analysis of Advanced Technology Industries Among OECD Nations." Prepared for Oak Ridge National Laboratory, 1988.

Stern, Robert M. "Changes in U.S. Comparative Advantage: Issues for Research and Policy." In Proceedings of the National Science Foundation Colloquium on International Economic Policy. Washington, DC, 1981.

Stoneman, P. The Economic Analysis of Technological Change. Oxford University Press, 1983.

Stoneman, P. "Theoretical Approaches to the Analysis of the Diffusion of New Technology." In The Trouble with Technology. Edited by S. Macdonald, et al. London: Frances Pinter (Publishers) Ltd., 1983.

Stoneman, Paul and Norman Ireland. "The Role of Supply Factors in the Diffusion of New Process Technology." Economic Journal supplement 93 (March 1983): 65-77.

Sutton, George P. Flexible Machining Systems. SRI International, August 1982.

Sveikauskas, L.A. "Technological Inputs and Multifactor Productivity Growth." Review of Economics and Statistics 63 (May 1981): 275-282.

Sveikauskas, Leo A. "Science and Technology in United States Foreign Trade." Econ. J. 93, 371 (September 1983): 542-554.

Tanssig, L. Economic Theory of Value. London: Pragg Publisher, 1920.

Tassey, Gregory. "Competitive Strategies and Performance in Technology-Based Industries." J. Econ. Bus. 35, 1 (1983): 21-40.

Tatom, J.A. "Domestic vs. International Explanations of Recent U.S. Manufacturing Developments." Fed. Res. Bank St. Louis Rev. 68, 4 (April 1986): 5-18.

Teece, David J. "The Market for Knowhow and the Efficient International Transfer of Technology." The Annals of the American Academy of Political and Social Science 485 (1981).

Teece, D.J. "Organizational and Technological Factors in the Theory of the Multinational Enterprise." In The Growth of International Business. Edited by M. Casson. London: Allen and Unwin, 1983, pp. 51-62.

Tharakan, P.K.M., ed. Intra-industry Trade: Empirical and Methodological Aspects. Advanced Series in Management, Volume 4. New York, Amsterdam and Oxford: North-Holland, in the U.S., New York: Elsevier Science, 1983.

Tharakan, P.K.M. "The Intra-Industry Trade of Benelux with the Developing World." Weltwirtschaft Arch. 122, 1 (1986): 131-149.

Thirlwall, Anthony P.A. "Trade Strategy for the United Kingdom." J. Common Market Stud. 22, 1 (September 1983): 1-16.

Thomas, E. "Recent Research on R&D and Productivity Growth: A Changing Relationship Between Input and Impact Indicators?" Paper for the Third Conference on Science and Technology Indicators. OECD, Headquarters, September 1984.

Tilton, John E. International Diffusion of Technology: The Case of Semiconductors. Washington, DC: The Brookings Institute, 1971.

Tirman, J., ed. The Militarization of High Technology. Cambridge: Ballingen Publishing Company, 1984.

Tisdell, C.A. Science and Technology Policy: Priorities of Governments. London: Chapman and Hall, 1981.

Turner, Philip P. "Import Competition and the Profitability of United Kingdom Manufacturing Industry." J. Ind. Econ. 29, 2 (December 1980): 155-166.

UNESCO. "Science Policy and Organization of Research in the Federal Republic of Germany." Paris: UNESCO, 1969.

UNESCO. "National Science and Technology Policies in Europe and North America: 1978." Science Policy Studies and Documents, No. 43, 1979.

UNESCO-CODATA. "Inventory of Data Sources in Science and Technology, A Preliminary Survey." Committee on Data for Science and Technology of the International Council of Scientific Unions. New York: Unipub, 1982.

U.S. Congress. "The Machine Tool Industry and the Defense Industrial Base." Hearing before the Joint Economic Committee. Washington, DC: GPO, 1983.

U.S. Congress. "Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Committee on Armed Services, United States Senate, Testimony on Space Defense Matters in Review of the FY1985 Defense Authorization Bill." S. Hrg. 98-724, Pt. 7.

U.S. Congress, Joint Economic Committee. Location of High Technology Firms and Regional Economic Development. Washington, DC: G.P.O., 1982.

U.S. Congress, Joint Economic Committee. International Competition in Advanced Industrial Sectors: Trade and Development in the Semiconductor Industry. Washington, DC: G.P.O., 18 February 1982.

U.S. Congress. Priorities and Efficiency in Federal Research and Development: A Compendium of Papers Submitted to the Subcommittee on Priorities and Economy in Government. Joint Economic Committee. Washington, DC: Government Printing Office, 1976.

U.S. Congress. "The Ailing Defense Industrial Base: Unready for Crisis." Report of the Defense Industrial Base Panel of the Committee on the Armed Services, House of Representatives, Ninety-Sixth Congress Second Session. Washington, DC: Government Printing Office, 31 December 1980.

U.S. Congress. Science, Technology and American Diplomacy. House Committee on Science and Technology. Washington, DC: U.S. Government Printing Office, 1984.

U.S. Department of Commerce. A Report on the U.S. Semiconductor Industry. Washington, DC: G.P.O., 1979.

U.S. Department of Commerce. An Assessment of U.S. Competitiveness in High Technology Industries. Washington, DC: G.P.O., 1983.

U.S. Department of Commerce. "Japanese Industrial Policies and the Development of High Technology Industries: Computers and Aircraft." February 1983.

U.S. Department of Commerce, International Trade Administration. The Robotics Industry. Washington, DC, April 1983.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Advanced Ceramics Industry." Washington, DC, March 1984.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Manufacturing Automation Equipment Industries." Washington, DC, June 1984.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Fiber Optics Industry." Washington, DC, September 1984.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Software Industry." Washington, DC, December 1984.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Ball and Roller Bearings Industry." Washington, DC, February 1985.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Semiconductor Manufacturing Equipment Industry." Washington, DC, March 1985.

U.S. Department of Commerce, International Trade Administration. "A Competitive Assessment of the U.S. Flexible Manufacturing Industry." Washington, DC, July 1985.

U.S. Department of Commerce, National Bureau of Standards. Overview of Artificial Intelligence and Robotics, Volume 2: Robotics. Washington, DC, March 1982.

U.S. Federal Trade Commission. Staff Report on the Semiconductor Industry. Washington, DC: U.S.G.P.O., 1977.

U.S. General Accounting Office. University Funding. GAO/RCED-86-53. Washington, D.C. 1986.

U.S. House of Representatives. Technology Policy and Its Effect on the National Economy. Washington, DC: G.P.O., 1987.

U.S. House of Representatives, Ways and Means Committee, Subcommittee on Trade. Competitive Factors Influencing World Trade in Semiconductors. Washington, DC: G.P.O., 1980.

U.S. International Trade Commission. "Competitive Assessment of the U.S. Metalworking Machine Tool Industry." USITC Publication 1428. Washington, DC, September 1983.

U.S. International Trade Commission. "Foreign Industrial Targeting and Its Effects on U.S. Industries, Phase I: Japan." USITC Publication 1437. Washington, DC, October 1983.

U.S. International Trade Commission. "Competitive Position of U.S. Producers of Robotics in Domestic and World Markets." USITC Publication 1475. Washington, DC, December 1983.

U.S. International Trade Commission. "Foreign Industrial Targeting and Its Effects on U.S. Industries, Phase II: The European Community and Member States." USITC Publication 1517. Washington, DC, April 1984.

U.S. International Trade Commission. "Competitive Assessment of the U.S. Ball and Roller Bearing Industry." USITC Publication 1797. January 1986.

U.S. International Trade Commission. Competitive Factors Influencing World Trade in Integrated Circuits. Publication 1013. Washington, DC: ITC, 1979.

U.S. International Trade Commission. "Competitive Assessment of the U.S. Metalworking Machine Tool Industry." Washington, D.C.: ITC, September 1983.

U.S. International Trade Commission. Competitive Position of U.S. Producers of Robotics in Domestic and World Markets. Washington, DC: ITC, December 1983.

U.S. Senate. U.S. Machine Tool Industry: Its Relation to National Security. Joint Hearing before the Committee on Foreign Relations and the Subcommittee on Energy, Nuclear Proliferation and Government Processes of the Committee on Governmental Affairs, 28 November 1983. Washington, DC: G.P.O., 1984.

van Walferen, Karel. The Enigma of Japanese Power. New York: McGraw Hill, 1989.

Vernon, R., ed. The Technology Factor in International Trade. New York: NBER/Columbia University Press, 1970.

Vernon, Raymond. "The Location of Economic Activity" In Economic Analysis and the Multinational Enterprise. Edited by John H. Dunning. New York: Praeger, 1974, pp. 89-114.

Vernon, Raymond. "A Strategy for International Trade." Issues 2 (Winter 1988-89): 86-91.

Vernon, R. and W.H. Davidson. "Foreign Production of Technology-Intensive Products by U.S.-Based Multinational Enterprises." Working paper, Graduate School of Business Administration, Harvard University, Boston, 1977.

Viner, J. Studies in the Theory of International Trade. New York, 1937.

Wallerstein, Mitchel B., ed. Scientific and Technologic Cooperation Among Industrialized Countries, The Role of the United States. Office of International Affairs, National Research Council. Washington, DC: National Academy Press, 1984.

Ward, David. "The Rise and Rise of Transnational Companies." Science and Public Policy. 12, 2 (April 1985): 84-87.

Waterson, Michael and Arcesio Lopez. "The Determinants of Research and Development Intensity in the U.K." Appl. Econ. 15, 3 (June 1983): 379-391.

Webbink, D.A. "The Semiconductor Industry: A Survey of Structure, Conduct and Performance." Staff Report to the Federal Trade Commission, 1977.

Weinsten, Uenohara and Linvill, "Technological Resources." In Competitive Edge: The Semiconductor Industry in the U.S. and Japan. Edited by Daniel I. Okimoto, T. Sagano, and F.B. Weinstein. Stanford: Stanford University Press, 1984.

Wheeler, Jimmy W., Merit E. Janow and Thomas Pepper (with contributions by Midori Yamamoto). "Japanese Industrial Development Policies in the 1980's: Implications for the U.S. Trade and Investment." Report prepared for the Department of State by the Hudson Institute, October 1982.

Willett, Thomas. "Thinking About Industrial Policy: The Political and Economic Dimension." Working paper, Claremont Center for Economic Policy Studies, 1984; and Society (November/December 1984): 13-15.

Wilson, Robert W., Peter K. Ashton and Thomas P. Egan. Innovation, Competition and Government Policy in the Semiconductor Industry. Lexington, MA: D.C. Heath and Company, 1980.

Wiesner, Jerome B. "On Science Advice to the President." Scientific American 260, 1 (January, 1989): 34-40.

Winter, Ralph E. "Research Spending in U.S. To Slow in 1989." The Wall Street Journal (21 December 1988): B3.

Wright, Robert. "Rationale, History and Implications: The US Experience." Science and Public Policy 11, 1 (February 1984): 7-9.

Wriston, Walter B. "Technology and Sovereignty." Foreign Affairs 67, 2 (Winter 1988/89): 63-75.

Yamamura, K. "Japan's Industrial Practices." Technology (July 1989).

Yano Research Inst. New Ceramics Market in Japan. Tokyo: Information Resarchers Inc., 1983.

Young, John A. "Technology and Competitiveness: A Key to the Economic Future of the United States." Science 241 (15 July 1988): 313-316.

Zahm, C.E., et al. "A Summary of Suggestions and Recommendations Made to MOTC by Tel & Tel Division." General Headquarters Supreme Commander for the Allied Powers Civil Communications Section, Tel & Tel Division. Tokyo, Japan, 12 May 1951.

Zuckerman, Lord. "Advise by a Science Adviser on How to Give Science Advise." Scientific American 113 (September 1988): 111-115.

Zuscovitch, E. "La dynamique du developpement des technologies: Elements d'un cadre conceptuel" ("The Economic Dynamics of Technologies Development" with English summary) Revue Econ. 36, 5 (September 1985): 897-915.

Zysman. Governments, Markets and Growth: Financial Systems and the Politics of Industrial Change. Ithaca, NY: Cornell University Press, 1983.

