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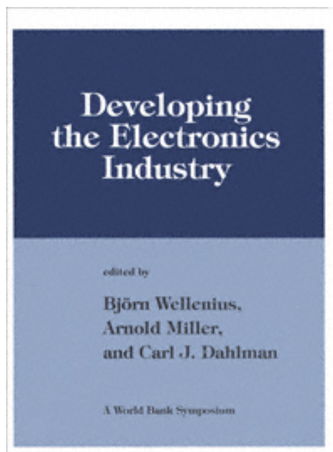

Developing the Electronics Industry

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A World Bank Symposium

Developing the Electronics Industry

Edited by
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PREFACE

Building up a capability in electronics is essential to the efficiency of any country's economy and its international competitiveness. Electronics is not only one of the fastest−growing industries worldwide, but it also has a profound effect on all other industries and throughout the economy by increasing productivity, changing cost structures, enabling development of new enterprises, and creating new competitive opportunities and challenges. Making the right policy and strategic decisions at both the national and enterprise levels is critically important in any effort to develop the electronics sector. At a minimum, there is the need to select, adopt, and adapt electronics technologies from world−wide sources for application in other sectors of the economy. At most, countries aspire to arrive or stay at the cutting edge of new developments in electronics and to have a strong presence in world markets. Most countries are somewhere in between. In the last two decades, newly industrialized countries have made major inroads into markets that were dominated earlier by only a few big players. An increasing number of developing countries are trying to move along the same path.

Yet the policy and strategy decisions are complex, the preferred choices are rarely clear cut, and both the risks and stakes can be very high. The electronics industry is highly dynamic, involves major capital outlays in research and development and in manufacturing plants, requires a substantial industrial and quality−assurance infrastructure and a skilled labor base, and is a truly global industry in which no one company—in fact, no single country or even region, nowadays—can any longer go at it alone. Nonetheless, opportunities exist for new entrants, critical success factors can be identified at national and enterprise levels, and in the context of appropriate policies, the electronics industry does offer viable choices for economic development.

This book examines the important interrelated issues involving market, technology, manufacturing, distribution, sourcing, and public policy that directly affect key players in the global arena of the electronics industry. Our efforts to put this book together began several years ago when the World Bank organized a three−week resident seminar in Washington, D.C. for senior Chinese government and industry leaders on becoming competitive in international electronics. Some 40 experts from industry, government, academia, and the World Bank presented lectures and participated in discussion groups. A series of policy workshops to assist participants in formulating national and enterprise polities and strategies for the development of a viable electronics industry was the capstone of the seminar.

The papers that were developed for the seminar proved so insightful and valuable to the participants that it was decided to make a selection more widely available in book form. This was found to be an ambitious task. To address the needs of a broader readership, it was necessary to expand most papers and to commission several new ones. Bringing all this material to press and keeping it up−to−date at one time truly tried the editors' endurance and the contributors' goodwill.

The result is a distinctly new product which we trust will be of value to government officials interested in formulating strategies to aid in the development of a competitive electronics sector in their countries, to companies and entrepreneurs eager

to participate in commercial opportunities in this sector, and to international development organizations that provide policy advice and financial support.

We extend our thanks to all contributors for their material. Debra L. Miller, as consultant to the World Bank, helped finalize the manuscript, assisted by Alexander Hunt, Adam Webb, Chris Cochran, and Carmel Charles. Rebecca Kary was responsible for copyediting. Alice Dowsett managed production to camera−ready copy.

Lastly, the customary caveat; the views expressed in this book are those of the individual authors. These views are not necessarily those of the World Bank's management, executive directors, or member countries.

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Electronics and the Developing Economies: Introduction and Overview

Björn Wellenius

Electronics is essential to developing a competitive modern economy. It is among the world's largest and fastest−growing industries, is embedded in many capital and consumer goods, has altered the cost structures as well as the quality and productivity standards of most other industries, and enables a veritable revolution in communications and information that lies at the root of modern economic development. However, the electronics industry is complex, intensive in R&D and capital, highly competitive, rapidly changing, and of global dimensions. Although the medium−term general directions of change can be foreseen, the long−term evolution faces major market and technological uncertainties. Individual ventures may rise spectacularly and reap large rewards, but they also face high risks. The ability to react rapidly to market and technological opportunities, to build fast on otherwise ephemeral successes, to allow for failures, to invest heavily in preparing for the future, and to adjust enterprise and government strategies as domestic and international conditions change are all necessary features of a viable modern electronics industry.

This chapter provides an introduction to the array of features and issues that must be considered in any attempt to build up the electronics industry in a developing or newly industrialized economy (NIE). The chapter first examines the overall importance of electronics for an economy. Second, some features that characterize the electronics industry as a whole are outlined. This is done largely by drawing on features and examples that are discussed in more detail in later chapters dealing with particular countries and industry segments (to which some forward cross−references are made). Lastly, the reader is given a guided tour of the book's core material, and is provided a summary of each chapter and commentary on selected aspects.

Electronics and the Economy

The output of the electronics industry comprises a wide variety of products, ranging from the most sophisticated computer hardware and software, telecommunications equipment, industrial and military control systems, and medical diagnostic apparatus, to advanced video and audio equipment, to home appliances and a host of lesser consumption items. A classification of electronic products is in Appendix 1.1 at the end of this chapter.

Size and Growth of the Electronics Industry

The electronics industry accounts for a large and growing proportion of the world's product. Starting with about $20 million of annual production of radios and phonographs in the early 1920s, output of global electronics reached $700 billion in 1990 and is expected to reach about $1.3 trillion by the year 2000.[1] The value added by the electronics industry is growing at about 6 percent per year, compared with about 3.8 percent for all manufacturing industries and 3.1 percent for gross domestic product (GDP) (all in real terms). At this pace, by the year 2000 electronics will account for about 4 percent of world GDP and 14 percent of value added in manufacturing. Table 1.1 gives further details.

The electronics industry can be an important source of jobs. In 1991 in the United States, for example, 2.4 million persons were directly employed in the electronics industry—or 9 percent

Table 1.1
Electronics and World Products, Selected Years

	Trillions of 1988 US$			
Category	*1988 Actual*	*1994 Forecast*	*2000 Forecast*	*Projected annual growth rate (percent)*
World gross domestic product (GDP)	17.3	20.8	25.0	3.1

Value added by manufacturing	4.0	5.0	6.3	3.8
Value added by electronics	0.5	0.6	0.9	6.0
Electronics as a percentage of GDP	2.6	3.1	3.6	
Electronics as a percentage of manufacturing	11.3	12.8	14.4	

Sources and assumptions: GDP: Figure for 1988 obtained from World Bank database; projected at 3.1 percent real growth per annum, as shown for 1980−88 in the 1990 *World Bank Development Report* (WDR). Value added by manufacturing: 1987 actual manufacturing output taken from WDR projected at 3.8 percent per annum, which was the annual real growth rate in 1980−88 shown in WDR Table 2. Value added by electronics: In the absence of data, the table assumes that the value added by the electronics industry globally is about 70 percent of production. Actual world electronics production for 1988 (US$645 billion) is taken from *Yearbook of World Electronics Data 1990 —Emerging Countries and World Summary* , Oxford, England, Elsevier Advanced Technology, 1990. The same source forecasts the world market to grow by 5.8 percent per annum in 1990−93. Electronics International Corporation in 1989 forecast 6.0 percent growth from 1988 to 1994.

of all manufacturing workers. This was more than in any other manufacturing sector and three times the number employed in the automotive industry. A further 4 million workers supported and serviced electronics firms. In Japan, about 1.8 million people worked in the electronics industry (Thomson).

The relatively large size and rapid growth of the electronics industry reflects the extensive use of electronics in many other sectors. Of particular importance are the key role of electronics in the information economy, the widespread impact of electronics in industry generally, and mass consumption of electronic final goods.

Electronics and the Information Economy

Electronics is the enabling technology of the information economy. About half the value of the world's production of electronics equipment is in data processing and communications. Table 1.2 shows a breakdown of global electronics equipment production by main types. Information is regarded today as a fundamental factor of production, alongside capital and labor. In the 1980s, economic activities that mainly involve handling of information (as distinct from physical goods) accounted for one−third to one−half of GDP and of employment in Organization for Economic Cooperation and Development (OECD) countries; such activities are expected to reach 60 percent for the European Community in the year 2000. Figure 1.1 is representative of trends among developed countries: fast growth of the information work force coupled with moderate growth of other services, which offsets the rapid decline of the share of employment in agriculture and, more slowly, in industry. Information also accounts for a substantial proportion of GDP in the NIEs and the modem sectors of developing countries.[2] It can be argued that the gap between developed and developing countries is more and more determined by differences in the ability to participate in the world information economy.

Increasing dependence of economic activity off information, coupled with globalization of capital flows, trade, manufacturing, and other activities, has resulted in strong demand for better, more varied, and less costly communications and information services. Demand growth has been intertwined with rapid advances in microelectronics, software, and optics. These innovations have greatly reduced the cost of transmitting and processing information, changed the cost structures of many businesses, and made possible new ways of meeting a wider range of information needs.[3]

Electronics has opened up a vast range of new forms and concepts for handling information. For example, with advanced telecommunications and data systems, financial markets have become integrated into a worldwide, round−the−clock operation. Other major services have likewise acquired global scale and the capability of virtually instantaneous response. Examples are found in air trans−

Table 1.2
World Electronic Equipment Production by Type, 1990
(percent)

Type of Equipment	*Percent*
Data processinga	36
Industrialb	19
Consumer c	16
Transportation and military	15
Communicationd	14
Total	100

a . Computers, data storage subsystems, data terminals, input/output, dedicated systems.

b . Security, energy management, manufacturing systems, instrumentation, robot systems, medical equipment, commercial aviation, other.

c . Audio, video, personal electronics, applicances, other.

d . Customer premises, public telecommunications, radio, broadcasting and studio, other.

Source: Dataquest, 1987 forecasts for North America, Europe, and Japan (about 85 percent of world market).

portation, insurance, and wholesale trade. Automation has changed the way business and government offices are organized and staffed. For example, large corporations are able to decentralize operations worldwide while strengthening central management. Thus, although the information sector already existed and experienced considerable growth in developed countries well before the use of electronics became widespread (see Figure 1.1 prior to 1960), it is the development and convergence of telecommunications and computers through electronic digital technology that have propelled the information economy into preeminence and global dimension.

Electronics and Other Industries

Nowadays, the competitiveness of any industry is significantly conditioned by its ability to incorporate electronics. A number of mechanical and electromechanical components of capital and durable consumer goods have been replaced by lower−cost, more versatile, and compact electronics solutions. Examples include telecommunications switching equipment, electric motor speed controls, pressure and temperature gauges, and automobile ignition and control systems. Moreover, electronics enabled the development of essentially new functions that have revolutionized industry. Numerical machine tools and textile looms, computer−controlled chemical and mineral processing

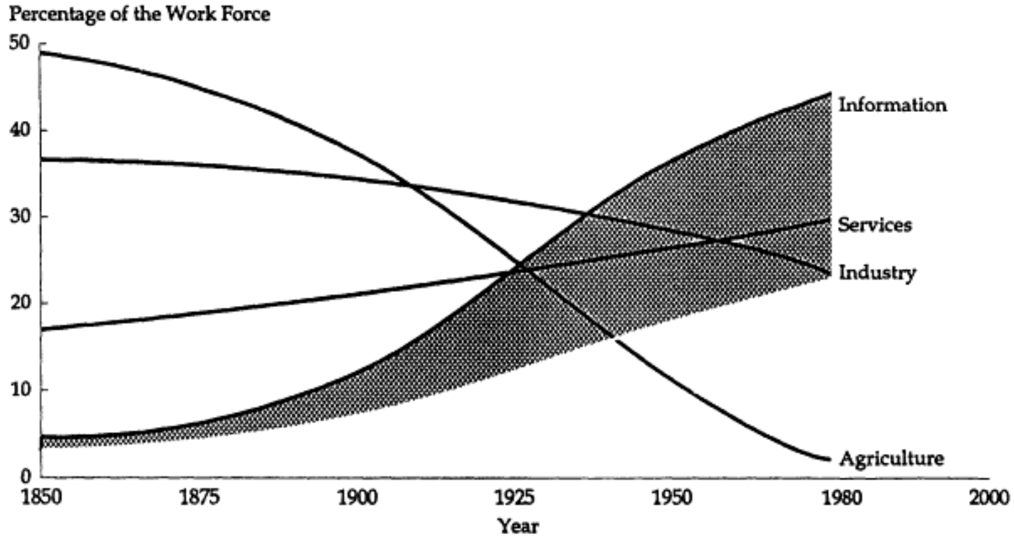

Figure 1.1
Distribution of the Work Force in Developed Countries by Economic Sector, 1850−1980
Note: Solid lines are for the United States. Shaded area illustrates the range of available data on the information sector's share of employment for Australia, Germany, Japan, Sweden, the United Kingdom, and the United States.
Source: Data cited in M. Jussawalla and D.M. Lamberton, *Communication Economics and Development* , Pergamon, 1982.

plants, and computer−aided design and manufacturing are some examples.

These innovations have, in turn, altered the cost structures and performance standards of many industries. In particular, factory automation has decreased the relative importance of manual labor, enabled flexible manufacturing lines that adapt quickly to different products, and resulted in better and new products manufactured at lower cost. Telecommunications networks can now be managed from central places, increasing efficiency and reliability and reducing on−site staff requirements.

Consumer Electronics

Electronics has also built up a large clientele among final consumers. Rapidly declining costs, high rates of product innovation, and high price and income elasticities of demand have resulted in the development of large and dynamic markets for electronics consumer goods. Over $60 billion worth of consumer electronics were produced worldwide annually in the early 1990s (Hart). This mainly includes radio and television receivers, video cassette recorders, personal computers, digital disc players, and video cameras, as well as a host of smaller items, such as microwave ovens, video games, watches, calculators, thermostats, digital clinical thermometers, musical greeting cards, and many other products.

The fast pace at which the consumer electronics market moves is especially noticeable with the arrival of new generations of products. For example, world sales of compact disk players roughly doubled each year—from $200 million in 1983, when they were first marketed, to $3 billion in 1987. Cross−country comparisons suggest that electronics consumption per capita grows about 50 percent faster than GDP per capita.4

Features of the Electronics Industry

Some characteristics apply across the whole electronics industry: rapidly declining costs, fast pace of technological innovation, high R&D expenditure, capital intensity, global reach, and government intervention.

Rapidly declining costs. Electronics is the declining−cost industry *par excellence.* Competition, intensive R&D, and rapid technological change and commercialization have driven costs down continuously during more than four decades (Dahmen, Ambrose), and this trend shows no signs of abating. The cost per function of electronic devices has decreased at a sustained fast rate without precedent in industrial history (Flamm). Declining costs largely result from rapid growth in the functional capability of the basic devices with which electronic systems are built. For example, the number of active elements per semiconductor chip increased from 1 (a transistor) in 1950 to 1,000 in 1970 to over 4 million in 1990, while the price per chip remained roughly constant (Dahmen). Consequently, the average price per function of integrated circuits has halved every year—from over $1 in 1965 to about 0.01 cents in 1990.[5]

Fast pace of technological innovation. Electronics features an exceptionally high rate of technological progress. For example, successive generations of semiconductors are only two to three years apart (Nishi). Products typically go from inception to market decline in about five years (Dahmen). Product innovation is closely linked to rapid progress in both design tools and mass manufacturing technologies (Miller, Dahmen). The success of any electronics enterprise hinges on arrangements to continuously acquire, adapt, and develop technology. To maintain a competitive position, as new products using the latest technologies reach the market, the next generation of technologies must already be under development.

High R&D expenditure . Rapid technological change is associated with high expenditures in R&D. For example, in the 1980s U.S. electronics firms overall applied about 8 percent of sales to R&D, almost four times the average for all manufacturing industries (Thomson). Worldwide, both computer and semiconductor manufacturers spent in R&D between 10 percent and 15 percent of sales (Dahmen, Flamm, Steinmueller), more than any other industrial subsector. In the late 1970s, the Japanese semiconductor industry invested in the very large scale integrated (VLSI) circuit program alone about 13 percent of sales and a further 8 percent contributed by the government (Nishi). Furthermore, R&D costs have been steadily rising. For example, the design of a first−generation microprocessor cost about $0.3 million, whereas that of a third−generation device reached about $100 million. Development of a new family of digital telephone switches in the 1980s cost in excess of $1 billion.

Capital intensity . The electronics industry is also capital−intensive. In manufacturing, large investments are needed in testing and quality control facilities, as well as in automated manufacturing equipment. For example, in the late 1980s, the U.S. electronics industry incurred capital expenditures of almost $30,000 per production worker, or about four times the average for all manufacturing industries. The average capital requirement of semiconductor manufacturing worldwide has risen from about 5 percent of sales in 1975 to about 20 percent in 1990 (Dahmen, Steinmueller).

Global reach. Electronics is by now a truly global industry. Research and development, design, manufacturing, sales, and corporate management of electronics firms are often located in different countries. Subsystems, parts, and materials for the manufacture of electronics equipment are sourced worldwide (Kimmel). Despite global competition for final markets, countries depend on one another for the supply of specific technologies and components. Scientific and technological breakthroughs in one part of the world are sometimes developed into commercial products in other regions (Sandholtz). National and even regional markets are no longer large enough to support local industry (Ambrose, Sandholtz). Firms across the world enter into strategic alliances, joint ventures, equity participation, marketing agreements, and other arrangements as part of their technology and marketing strategies (Miller, Thomson, Mody).

Government intervention. Governments have played active roles in all countries or economies that have attempted to develop an electronics industry (Dahlman). The importance of electronics for industry and defense has led governments of developed countries to support the electronics industry (Thomson, Sandholtz). In developing countries, the governments have been particularly interested in the potential of electronics to generate employment and exports, attract foreign investment, and help build up a domestic technological base and skilled human resources. Industrial and military development programs, trade, tax, and investment policies, financial assistance, and direct participation of the state in R&D and production, are among the instruments used by governments to these ends (Dahmen, Simon, Mody, Dahlman).

Interplay Among Segments of the Electronics Industry

The character of the electronics industry is shaped by the interplay among the features discussed above. For example, technological innovation offers the potential for lower costs, but lower costs only materialize with high sales volumes, which in turn generate surpluses to help finance the next round of technological development and capital investments in manufacturing plant. Although distinctions among subsectors of the electronics industry facilitate the presentation and give focus to the discussion, they do not reflect a clear−cut segmentation of the industry. In this book, for example, we refer especially to semiconductors, computers, consumer electronics, and telecommunications equipment. However, these categories in the first place are neither homogeneous nor complete. For example, the semiconductor industry mainly comprises firms that manufacture semiconductors and firms that produce the equipment needed to manufacture semiconductors (Dahmen), which are two very different types of firms. Besides semiconductors, a host of other components, such as discrete passive components (for example, capacitors and resistors), in contrast with semiconductors, use mature and fairly stable technologies (Gowen and Hefler). Second, whole families of products may be viewed either as separate categories or as scattered among other categories. For example, several of the contributors to this book refer to "industrial electronics" (for example, automotive and controls) as a subsector, while others include these products under semiconductors and computers. For purposes of structuring this book, we have chosen the latter approach. Third, with changes in technology and markets, products migrate readily from one category to another. For example, telephone sets, electronic typewriters, and low−end personal copiers, facsimile machines, and computers, all once marketed and serviced as specialized telecommunications and office equipment, have become consumer goods sold by department stores, discount stores, and mail order firms. The convergence of computer and cellular telecommunications technologies is leading to a new generation of portable data capabilities that fits neatly in neither category and may anyhow be heading toward becoming another commodity (Hart, Ambrose). Rather, some of the most important lessons regarding electronics industry policy and strategy result from understanding the interplay among various industry segments.

Close Interactions Along the Industry Chain

Whereas in the past, the functions of R&D, design, manufacturing, sourcing, distribution, end user application, and service were carried out in sequence and rather independently from one another, integration is now essential (Miller, Thomson). For example, the introduction of solid state technology in color televisions was accompanied by automation of manufacturing and by strategic changes in marketing and after−sales service (Hart). The development of new generations of integrated circuits has

been related to improvements in computer−aided design, engineering, and flexible manufacturing (Dahmen). Wafer materials producers work closely with semiconductor manufacturing equipment producers and with semiconductor manufacturers in order that advanced devices can be produced reliably at low cost (Thomson). Structural changes in the provision of telecommunications networks and services in recent years have resulted in major realignments all along the telecommunications equipment industry chain (Ambrose). One consequence of this close integration is that problems in any segment propagate along the chain and may affect the whole industry (Thomson).

Improvements in One Industry Segment Benefit Others

There is considerable movement of technology among electronics subsectors. For example, controls and software developed for computers have been applied to consumer electronics, while techniques for high−volume manufacturing of consumer goods have been adopted by the computer industry (Miller). Economies of scale achieved in one industry segment benefit others as well. For example, large−volume production of advanced consumer equipment result in low−cost components that are also used in computer, telecommunications, medical, and military equipment (Hart).

Firms of Different Sizes Play Complementary Roles

The market features a wide range of enterprise sizes. For example, in the computer industry, large firms long in the business dominate established markets through economies of scale and scope, while small start−up firms pioneer new products and markets (Flamm). Semiconductors are produced both by large, integrated firms covering broad markets and by firms competing in small, highly advanced, specialized niches (Dahmen). In 1991 there were about 25,000 electronics manufacturing firms in the United States, of which 95 percent were relatively small firms with assets of less than $10 million, and about 40,000 software firms that had an average of only 10 employees per firm (Thomson).

Competition Coexists with Cooperation

The modern, global electronics industry is highly competitive, yet firms that are rivals increasingly choose to collaborate for specific purposes. Strategic alliances are formed for technological development, manufacturing, and marketing (Miller, Flamm). For example, in response to large cyclical variations in sales, semiconductor manufacturers have formed close relationships with their customers to ensure deliveries in exchange for greater predictability of demand (Dahmen). Regional cooperative programs seek to overcome the limited success of individual countries in building up globally competitive industries (Sandholtz). International standards are a key determinant of industry growth (Miller, Flamm). For example, global and regional network standards have been developed by the International Telecommunication Union with the close participation of all major equipment suppliers since the inception of the industry, and by industry and standards organizations in the United States, Europe, and Japan.

Changing Determinants of Competitive Advantage

The interplay among features of the electronics industry has been accompanied by changes over time in the determinants of competitive advantage of firms and countries. An economy's potential to develop a modern electronics industry today is critically conditioned by availability of educated personnel, an industrial infrastructure of suppliers, R&D, and quality assurance, and a public policy environment conducive to internationally competitive industry (Miller). A firm's competitiveness is largely built up through technology and market strategies. Labor cost, once a major determinant of manufacturing location, is now relatively unimportant compared with technology and capital as factors of production. In the United States, for example, direct labor today accounts for only 5−10 percent of manufacturing costs (Thomson). Also, low wages of unskilled workers are often offset by low labor productivity and high transportation and management costs (Gowen and Hefler).

These changes in the determinants of competitive advantage have been accompanied by shifts in world market shares of producers and by changing requirements and opportunities for new entrants. Successful new players have entered the electronics industry and then moved upscale, pushing the erstwhile dominant players to develop new generations of technologies and products in order to maintain or regain competitive positions, and vacating low−end openings for a new wave of entrants. The electronics industry was for decades the exclusive province of the most advanced economies of North America and Europe where the technologies and large markets first developed. From the 1960s, however, the expansion of manufacturing capacity shifted to NIEs in search of lower−cost labor. These economies, in turn, gained important new sources of employment, foreign investment, exports, and industrial skills. Gradually the new players moved up from labor−intensive assembly of relatively simple products on behalf of

foreign firms using mature technologies, to more sophisticated processes and products and direct involvement in technology development. They eventually established a presence of their own in international markets, competing with and partly displacing dominant producers in North America and Europe, as well as opening up new markets. At the same time, new technologies increasingly required costly and complex automated manufacturing and testing facilities and highly−skilled personnel. High−quality products became available in all market segments, including those of simple low−priced goods, and all new suppliers came to be expected to conform to high standards. The electronics industry likewise came to demand high standards from its own suppliers of goods (for example, components and materials) and services (for example, plastic molding).

The story repeats itself. The first major shift was from North America to Japan. Subsequent waves brought Hong Kong, the Republic of Korea, Tai−wan (China), and Singapore; Brazil, India, and Mexico; and more recently China, Indonesia, Malaysia, the Philippines, and Thailand. Many other developing economies have declared intentions to follow suit. Table 1.3 summarizes the shares of world electronics production by major economies and regions in 1990.

Table 1.3
World Electronics Production by Region, 1990

Region	*US$ billion* a	*Percent*
United States & Canada	218.0	32
Japan	204.0	29
Europeb	166.0	24
Other	105.0	15
Asian newly industrialized economies	54.8	7.9
China	12.0	1.7
Brazil	11.0	1.6
India	5.2	0.8
Malaysia	5.7	0.8
Mexico	4.6	0.7
Other c	11.7	1.7
Total	693.0	100.0

a . In 1988 U.S. dollars.

b . Excluding Eastern Europe and the former Soviet Union.

c . Mainly Australia, Indonesia, Israel, Philippines, and Thailand.

Source: Yearbook of World Electronics Data 1990—Emerging Countries and World Summary , Oxford, England, Elsevier Advanced Technology, 1990.

Book Overview

The central concern of this book is under what conditions, in which markets, and through what enterprise strategies and government policies, can a sustainable efficient electronics industry be built up in developing countries and in NIEs? The introduction to this set of issues is further developed in the chapter by Miller (chapter 2), who examines major trends in the global electronics industry especially regarding technology and manufacturing, identifies critical success factors for new entrants, and discusses selected elements of national and enterprise strategy. The main body of the book is then divided into four parts, dealing in more detail with industry characteristics, the experience of advanced industrial economies, the experience of NIEs, and conclusions on electronics development strategy and the role of government. An annex to the book outlines the organization of a public policy workshop as it took place with a group of senior government and industry officials.

Industry Characteristics

Part I of the book characterizes and quantifies the world electronics industry, with special reference to four major application areas: semiconductors, computers, consumer electronics, and telecommunications. Development of the modem electronics industry has been closely tied to that of semiconductors, and it can be argued that semiconductor technology will continue to drive advances throughout the electronics industry well into the next century. Dahmen (chapter 3)) focuses on the global semiconductor industry and its three main components, namely production of semiconductors, manufacturing of equipment to produce semiconductors, and distribution. He compares the semiconductor industries and government policies of the United States and Japan, and touches on Korea, Taiwan (China), and Europe. Dahmen concludes that the semiconductor industry will continue to change and grow rapidly, and that new entrants will face major hurdles in capital, technology, and policy. The chapter includes an appendix that briefly describes the world's 20 largest semiconductor producers.

The computer is a symbol of the extent to which modern life, in developed and developing economies alike, is shaped by electronics. It is, says Flamm (chapter 4), a revolutionary technological leap with extraordinary economic and social significance. Flamm reviews the main features of the computer industry as it has evolved in developed countries, and current trends toward further internationalization, standardization, protection of intellectual property rights, and strategic alliances. He then draws some concrete suggestions for policymakers in developing economies: facilitate widespread application of computers to benefit the economy; select a viable strategy in hardware by targeting applications where the economy has special needs or comparative advantage; emphasize systems integration, software, and maintenance; develop export markets as an essential step in the long−term survival of the industry; and focus on people as key factors of transferring and disseminating technology.

Consumer electronics lies at the center of the industry. It provides entry points for new players, training grounds for manufacturing and management skills, and high−volume, high−growth markets that generate economies of scale and scope which spill into other industry segments. Hart (chapter 5) argues that countries and firms that have understood the importance of consumer electronics as a generator of wealth, employment, exports, and technology did well in the last two decades, while those that failed to appreciate the dynamics of markets and technology were badly hurt. Hart discusses the global consumer electronics industry, and looks more closely at the United States, Europe, and Japan. He examines the world markets and production, the shift of market dominance in terms of technology and market strategies of the firms and government policies, and the potential role of new generations of products and services (particularly high−definition television) in the renovation of the industry. The success factors of any modern electronics industry are illustrated through the discussion of the dominance, decline, and prospects for recovery of U.S. consumer electronics.

Rapid electronics−based technological innovation and growing demand for more, better, new, and cheaper services, are the twin driving forces of a worldwide wave of structural reforms in the provision of telecommunications services under way from the early 1980s. Traditional monopolistic market structures are giving way to diversification of supply and to competition. The state, which (with the main exception of the United States) had owned and operated the telecommunications enterprises, is shifting this responsibility to the private sector while concentrating on policy and regulatory functions. These changes, argues Ambrose (chapter 6), had a major impact on the telecommunications equipment industry. Closed links between operators and manufacturers are giving way to fully commercial relationships, leading to accelerated innovation and lower costs. The equipment markets have become fiercely competitive and reached global dimensions. In major product categories (especially switching), only a handful of suppliers, all of them large multinational corporations capable of building a global market base, are remaining in the race. Ambrose particularly discusses technology trends, market segmentation by type of equipment, geographical distribution of production, and the prospects for technology and market consolidation. To conclude, he draws some policy implications for developing countries. As with computers, one lesson is that the large and widespread benefits to the economy from rapidly building up a modem, efficient telecommunications infrastructure should not be held hostage by an inefficient domestic telecommunications manufacturing industry. High prices and obsolescent equipment translate into high costs to the economy that more than offset the limited benefits of employment and foreign exchange savings realized by telecommunications industries that in many countries are still not fully exposed to the rigors and pressures of international competition.

Experiences of Advanced Industrial Economies

Part II of the book examines and compares the experiences in electronics development in the most advanced industrial economies—namely, the United States, the European Community, and Japan. It also looks more closely into the strategic importance of the integrated circuit industry in these economies, and discusses worldwide sourcing as a key feature of the modem electronics industry.

The U.S. electronics industry is the world's largest and, despite a decline in some segments, continues to grow in output, trade, technology innovation, productivity, creation of new firms, employment, and supply of key products to other industries. Thomson (chapter 7) provides a wealth of information and analysis of this industry. The viewpoint is close to that of major U.S. industry associations. Thomson first outlines the importance of the industry and its major characteristics, and compares it with the electronics industries of other world regions. Then he identifies technologies in which the United States holds or has the potential to develop a leading global position, and discusses the prospects for the U.S. industry under current and improved policy and market scenarios. Lastly, Thomson discusses major issues faced by the U.S.

electronics industry today, especially regarding investment capital, corporate culture and finance, education and training, antitrust law, and public policy. He makes a pitch for more concerted public policy measures and closer cooperation between government and industry that, he argues, would help place the U.S. electronics industry on a more level playing field relative to its major competitors around the world.

Although a number of modern electronics technologies were developed in Europe, the region has not been particularly successful at taking these technologies to world production levels. In chapter 8, Sandholtz gives a view of electronics in Europe and the changing roles played by national governments and European institutions. He describes how increasing concern in the 1960s about the ability of European firms to catch up with the United States (and later fend off Japan) led to individual governments attempting to develop "national champions." By the early 1980s, this strategy had proven to be largely ineffective, and gave way to specific pan−European collaborative efforts, which are explained in some detail. Sandholtz concludes that these efforts, while still not enough to match the challenges from the United States and Asia, considerably strengthened Europe's technology base.

Japan is often at the center of any discussion of how new players can triumph in electronics. Although Japan's competitive advantage was initially based on lower wages, its ultimate success was driven by technology and marketing strategies pursued through collaboration among enterprises and with the government. Nishi (chapter 9) tells about Japan's approach to development of the electronics industry using the VLSI program as a case study. The chapter allows the reader to see an example of the "Japanese miracle" through Japanese eyes. In response to a widening gap in technology between Japan and the United States that was considered a threat to the industry's survival the Japanese government and industry launched a ten−year program in the mid−1970s to develop and commercialize VLSI circuits. The program was successful not only in meeting its own objectives, but also in strengthening the development of basic technologies, achieving cooperation among rival firms, combining government support with competitive pressures on enterprise performance, and generally cementing a stronger base for subsequent progress in the industry. Some of the ways in which cultural differences among countries (specifically between Japan and the United States) have a bearing on the effectiveness of particular industry strategies are brought out in this chapter. Nishi also touches on the different roles that the military played in developing the industry in both countries.

To the extent that it can be argued that development of the modern electronics industry is closely linked with that of semiconductors, it is of interest to examine the strategic role of the integrated circuit (IC) industry on a cross−economy basis. This is what Steinmueller does in chapter 10. First he discusses the origins and strengths of the IC industry in the United States, which was the unchallenged global leader from the late 1940s when semiconductors were invented, to the late 1970s. Steinmueller highlights the role of market forces, on which U.S. government policy relies heavily to generate plentiful new technology initiatives, ease out quickly the least promising ones, and rapidly adopt and utilize successful innovations. The intense effort that focused on process technologies launched by Japan in the late 1970s allowed them to catch up with the United States in the 1980s in some leading IC products. The large size and integration of Japanese industrial conglomerates, government support, and big domestic markets permitted these firms to finance increasing investment costs and achieve economies of scale. Steinmueller then turns to Hong Kong, Korea, Tai−wan (China), and Singapore, and examines the contrasts between these economies in the structure of industry and government policy, especially on foreign investment and ownership, and how these contrasts reflect on the different courses followed by their respective IC industries. Finally, Steinmueller offers four "rules of thumb" for new entrants in the IC market: focus on areas of specialized advantage rather than on advanced processes; emphasize systems rather than components production; limit or avoid the use of domestic market protection; and use standard products to reduce costs while using application−specific products to build up a unique position in the international markets for system products.

Globalization of the electronics industry, decreased importance of labor in total cost, and shorter product life cycles, reflect in the practice of subsystem and component sourcing by the industry. Kimmel (chapter 11) reviews trends in worldwide subsystem sourcing, and the economic and strategic implications of these trends. The viewpoint is that of a major manufacturer of office equipment, which is also representative, Kimmel argues, of most electronics industries, especially in advanced consumer and industrial products. The traditional approach of selecting suppliers on the basis of the extent to which quality, cost, and delivery of inputs affects (changing) critical success

factors of the outputs, is giving way both to a simplified way of determining relevant costs and to the addition of two more factors, namely technology and service. Comparative cost analysis based on standard accounting methodology has become both too complex and often misleading, and Kimmel argues for its replacement by an analysis based on the cost of materials (inputs) and the cost of conversion (value added to transform the inputs into the desired products). The approach is illustrated by discussing the criteria used by Xerox to select suppliers of disk drives, and the response of Asian NIE suppliers. Some generalizations are made for establishing international sourcing and supply strategies.

Developing Economies and NIEs

Part III presents and compares the experiences of selected developing economies and NIEs. Simon (chapter 12) examines the emergence of the "four dragons" (Hong Kong, Republic of Korea, Taiwan [China], and Singapore) in the global electronics scene. The focus is on technology development as a key factor enabling these economies to move from low−cost manufacturing for transnational corporations to being primary producers of high−quality goods selling under their own names in the world markets. Foreign investment and technology strategies are found of particular importance in the development of the four economies' electronics industries. This is illustrated by a case study of Taiwan (China) and comparisons with Korea, Singapore, and Hong Kong. A central theme in this chapter is the importance of government interventions in essentially free−market economies, enhancing rather than substituting market forces— initiating and facilitating R&D, education, and industry restructuring programs, and helping firms deal with transnational corporations especially regarding foreign investment and technology transfer. Simon concludes by noting that all four economies face daunting challenges as they seek to further upgrade their electronics industries: growing barriers to entry (for example, cost of plant) in many high−technology products where they would want to become global players; increasing technological protectionism by current leaders; issues of trust, cross−cultural understanding, and politics in making international alliances work; inadequate infrastructure and human skills base to utilize new technologies in the domestic economies; and limited flexibility and responsiveness of the existing industrial structures.

Brazil and India are often mentioned as examples of developing countries that have succeeded in building up sizeable electronics industries. They are also cited, however, for the relatively low efficiency and low rate of innovation of their industries, and for the high costs that low efficiency and innovation have imposed on the rest of the countries' economies. Frischtak (chapter 13) looks at the Brazilian experience, focusing on four segments: semiconductors, banking automation, color televisions, and digital switching equipment for telecommunications networks. Despite a sizeable domestic market, over two decades of government and industry efforts, and relatively low wages and salaries, Brazil's electronics industry is far from internationally competitive. On the basis of his analysis of these four industrial segments, Frischtak concludes that Brazil should concentrate its limited technological, marketing, and financial resources on a smaller set of products. He advocates specialization across product lines, along the input−output chain, and among different production stages. Changes in corporate structure would be required to respond to new technological and market opportunities. The key to bringing about these transformations, says Frischtak, would be changes in public policy to provide incentives for the firms to improve their competitive standing in both domestic and international markets. These policies should focus on technology acquisition and development as much as on product development and manufacturing.

Gowen and Hefler (chapter 14) present the case of India. As in Brazil, the Indian electronics industry is fairly large, but generally not competitive by international standards. Process technologies are outmoded by up to 20 years, and prices of major electronics products are up to several times those in world markets. The industry suffers from excessive fragmentation, lack of competition and other incentives to improve performance, and unreliable and technologically weak industrial and service infrastructures. Government policy and regulation has also been a problem, especially with respect to restrictions on enterprise entry, location, and growth; high levels of indirect taxation; restrictions on foreign trade and investment; and reserve of large industry segments (especially telecommunications and defense) for the public sector. In the 1980s, the electronics industry improved Considerably following government steps to partially deregulate and liberalize industry and trade in general, facilitate the acquisition of foreign technology, and promote exports. Gowen and Hefler find that India could develop competitive production in several segments of the electronics industry on the basis of its substantial pool of skilled manpower, potentially large domestic market, relatively large industrial base, and number of Indians in management and technical positions abroad.

They suggest guidelines to identify potentially competitive industry segments, and conclude that the best prospects lie in industrial, computer, and telecommunications products that have a great impact on the performance of other economic sectors and are intensive in design, system integration, sales, installation, and maintenance; on consumer electronics products for which there is a large domestic market; and on passive components and relatively simple semiconductors.

Given the increasing importance of information in development, and given that electronics is the enabling technology of the information economy, developing economies and NIEs have taken a keen interest in building up the information industries. Mody (chapter 15) discusses alternative strategies pursued by five economies (Brazil, India, Korea, Taiwan [China], and Singapore) to develop industries that provide the hardware for the information sector—mainly data processing and communications equipment. One of the main questions addressed in this chapter is the scope of the industry. The conclusion from the five economies studied is that focusing on a few, relatively simple products is needed in the early stages to develop basic production and organizational skills and to grow fast, but a broader approach is then desirable to take advantage of technological complementarities and hedge against market and technological uncertainties. Another central concern is the role of government. The finding is that, given the potential externalities of the information industries and the difficulty of competing internationally, governments have intervened to promote domestic equipment manufacturing in all five economies. The extent and modalities of government intervention, however, have varied considerably among economies and with time; overall, governments have played more limited roles where private institutions are most developed, and the balance has shifted from government stimulus to industry linkages with international firms. The governments' participation in developing human and physical infrastructures is likely to continue to be of critical importance.

Conclusions: Development Strategy and Government Role

Given the wide variety of strategies and results, and the diversity of interpretations and prescriptions presented in this book, can we draw some generally applicable lessons for developing economies intent on building a modern, competitive electronics industry? The answer is generally affirmative, but a number of questions remain unsettled and need further investigation.

Dahlman (chapter 16) pulls together the experiences of four industrial countries (United States, United Kingdom, France, and Japan) and seven developing and newly industrialized economies (Brazil, China, India, Korea, Taiwan [China], Singapore, and Hong Kong). The strategies are characterized in terms of the extent to which a wide range of government instruments has been used to help develop the electronics industry. Dahlman offers a preliminary assessment of how well the various strategies have met their objectives and resulted in efficient, sustainable electronics industries, and identifies success factors.

One of the main conclusions is that successful strategies have combined some initial protection and nurturing of the industry with strong demands to improve performance. The latter has mainly resulted from exposure to domestic and international competition. Other elements of success include continuous access to foreign technology; a healthy domestic macroeconomic environment with good growth prospects and flexibility of capital and labor markets; and the quality and size of human resources, technology infrastructure, and private initiative and management.

Another conclusion is that governments have played essential roles. This mainly relates to helping develop human resources and basic technological infrastructures, and providing a policy environment that contains incentives for firms to improve their technological levels and facilitates adjustment of the industrial production structure. However, excessive government intervention was a factor of relatively poor performance of some countries, and in all cases the role of government has changed over time.

The chapter—and the book—concludes by raising several questions on which the lessons from experience are inconclusive and require further work. They include the relative merits of targeting technologies and subsectors, and how to make the right choices; technological complementarities and the merits of sequencing (incremental changes in the industry) as compared with leap−frogging (change by large steps); the extent to which strong export orientation will remain a viable option in the context of current trends toward regional trade blocks; and how the growing emphasis on intellectual property rights will affect access to new technology.

Final Remarks

Given the pervasive and increasingly critical role of electronics in economic development, all countries must possess some capability in electronics. In any economy, modern sectors require modern

equipment and services. Electronics provides cost−effective solutions for at least some productive activities in even the most modest economies. And maybe precisely because of their backwardness, it is in such countries that the returns from investing in building up a degree of mastery of electronics may be largest in relative terms.

At a minimum, all countries need to have some competence in understanding, selecting, acquiring, and using electronics technology. This involves developing human resources, especially through training and higher education. Building up a capability to use electronics, however, is not a trivial task, and goes well beyond instruction in the use of new equipment. In particular, it also involves maintaining effective contact with rapidly changing world technology and markets, and securing access to sources of specialized information and technical support. Some indigenous research and development activity may be needed, if only to support effective higher education.

Electronics industry continues to offer viable opportunities to new entrants. The success stories of the past, however, while containing important lessons, cannot be readily replicated today. In particular, inexpensive labor is no longer a major factor in attracting electronics manufacturing. Irrespective of low prices, today there is no market for poor−quality products. Electronics industries established as enclaves without an appropriate industrial hinterland, have only limited growth potential and economic development impact. Lack of competitive pressure and of sustained access to technology lead to high costs and antiquated products that impose a heavy burden on the rest of the economy.

Significant questions of strategy and policy emerge even for countries that have no electronics industry of their own. Rapid technological obsolescence calls for hard choices between investing in the latest proven imported electronics technology, which is frequently the most appropriate technology in terms of equipment cost, space, and maintenance requirements, functional capabilities, and availability and cost of spare parts and additions, and continuing to use and expand existing plant, including equipment already in place and still in good working order.

A particularly intractable set of policy issues arises in the field of informatics. The increasing use of computers and information services, and the convergence of these with telecommunications, broadcasting, publishing, and other traditionally separate activities, offer important potential gains even to very underdeveloped economies. Achieving these gains, however, may require approaches that cut across traditional sectors and institutions, and may need government guidance and initiative. But precisely because informatics does not conform to established divisions of responsibility, and because it is a relatively new field in which experience is limited, formulating and implementing policy is more difficult than in traditional sectors.

Notes

1. A billion is 1,000 million.

2. Loosely speaking, the information sector comprises all activities that involve the production, processing, and distribution of information and knowledge, as distinct from physical goods. It includes activities that primarily comprise the handling of information, such as banking and government, as well as the information components of other activities, such as accounting in a factory and management of a farm. The information sector thus in−dudes activities traditionally counted under the primary, secondary, and tertiary sectors. The information sector has been quantified by a number of researchers in the United States, Europe, and Japan, since the 1950s. Data for developing countries is more limited. However, several studies in the Asia and Pacific region in the early 1980s, using data from the late 1970s, give some indicative figures of the information sector as proportion of GDP, e.g., Singapore 25 percent, Indonesia 19 percent, Malaysia 14 percent. See *Information Activities, Electronics and Telecommunications Technologies* , OECD, 1981; M. Jussawalla and D. M. Lamberton, *Communication Economics and Development,* Pergamon, 1982; and M. Jussawalla, D. M. Lamberton and N. D. Karunaratne, *The Cost of Thinking: Information Economies in Ten Pacific Countries* , Ablex, 1988.

3. The text of this and the preceding paragraph is adapted from B. Wellenius and others, "Telecommunications: World Bank Experience and Strategy," World Bank, Discussion Paper No. 192, March 1993.

4. For example, 1983 data for a cross−section of 17 countries, ranging from India, Indonesia, and the Philippines to Japan, the United States, and Sweden, showed per capita electronics consumption varying at about 1.5 times the per capita GDP. Under certain conditions it may be assumed that changes in consumption in any one economy over time follow the same pattern as these variations among countries at a given time.

5. Unless otherwise indicated, prices are in current terms. Adjusted for general price inflation, the price has further declined by a factor of three or four since the 1950s. Therefore, the real decline of the costs of electronics products over time has been even greater than stated here and at various other places in this book.

Appendix 1.1 Electronics Industry—Main Product Categories

1. Consumer Electronics

Video equipment

Monochrome TV

Color television

Advanced television

Projection TV

Video systems

Videocassette recorders and players

Camcorders

Personal video

Still video cameras

Videodisc systems

Video software

Videotex systems

Captioning

Home satellite earth stations

Audio equipment

Audio components

Digital audio

Add−on components

Packaged audio systems

Audio accessories

Audio tape equipment

Autosound

Portable audio

Radio

Home information equipment

Home computers

Computer software

Computer accessories

Dedicated word processors and typewriters

Compact facsimile

Personal copiers

Telephones

Cellular telephones

Electronic organizers

Accessories

Communications

Other consumer electronics products

Electronic watches

Toys and games

Musical instruments

Electronics for children

Home security systems

Health care products

Calculators

CEBus or intelligent home

2. Communications Equipment

Central offices

Fiber optics

Facsimile

Microwave transmission

Telephones and answering machines

Cable television

Cellular radio

PBX, Centrex, and key systems

Data communications

Modems

Networks

Integrated systems digital network

Network management systems

Local area networks

Wide area networks

Value−added networks

Metro area networks

Teletext/videotex

Land mobile radio

3. Computers and Industrial Electronics

Computers

Personal computers

Workstations

Minicomputers and super−minicomputers

Mainframes

Mini−supercomputers and supercomputers

Peripheral equipment

Storage equipment

Optical disk technology

Computer terminals

Printers

Software and operating sytems

Industrial automation

Industrial controls

Electronic temperature controls

Artificial intelligence

Robotics

Machine vision

Materials handling

Bar coding

Computer−Aided Design/Computer−Aided manufacturing/computer−aided engineering/computer integrated manufacturing

Testing, measuring, and analyzing equipment

Power supplies

Nuclear electronic equipment

Medical electronics

Diagnostic equipment

Therapeutic equipment

Surgical and medical instruments

Patient monitoring equipment

Consumer medical electronics

4. Electronic Components

Electron tubes

Television picture tubes

Receiving tubes

Power and special purpose tubes

High vacuum, gas and vapor, and other special purpose tubes

Electro−optical devices

Microwave tubes

Solid state products

Discrete semiconductors

Integrated circuits

Other semiconductor devices

Electronic parts

Capacitors

Resistors

Networks

Switches and relays

Electronic parts (continued)

Accessory parts

Connectors

Transformers

Quartz devices

Filters

Printed−circuit boards

Wire and cable

5. Electronic−Related Products and Services

Aerospace

Automatic controls

Systems integration and computer services

Motor vehicles

Electronic−related office equipment

Photographic and optical equipment

Photographic equipment

Optical equipment

Toys, games, clocks, and musical instruments

Toys and games

Clocks and watches

Musical instruments

Source: 1990 Electronic Market Data Book , Electronic Industry Association, Washington, D.C. 1990.

2—
Building a Modem Electronics Industry

Arnold Miller

Among all industrial sectors, electronics is one of the most dynamic. Continuously changing technology, production methods, market opportunities, distribution channels, service resources, and competitive pressures challenge companies and governments alike. These features of electronics industry also give rise to striking new opportunities with widespread impact on a country's entire economy and quality of life. In particular, electronics has a major leveraging effect on the industrial base of a country, whose competitiveness nowadays depends on the use of electronics and related technologies. Conversely, the multitude of alternative investment choices and the cost of failure make the decision processes complex and daunting.

Can a developing or newly industrialized country (NIE) become a serious player in the global electronics industry? How? Some policymakers and analysts believe that the obstacles are too high and the risks are too great for latecomers to effectively enter this industry. Technological changes and shifts in market shares have reduced the long−term importance of cheap labor, once the primary determinant of competitive advantage for low−income countries. Entry costs are high and rising, in terms of investment in plant, supporting infrastructure, and marketing and distribution arrangements. Global competition is intensifying. Nonetheless, NICs and several developing countries have already built up functioning electronics sectors and are intent upon their expansion. Most of them are promoting exports in order to support sector growth. To compete effectively, enterprises are entering into new forms of national and global alliances. In some cases, economies of scale and giant factory structures have become less critical than before, whereas the ability to customize and respond rapidly to client needs has become more important.

This chapter outlines trends and issues in the development of strategies for the electronics industry, with particular emphasis on their implications for recent entrants. First, a review of characteristics of the world electronics industry is offered. Second, the outlook for changes in technology, manufacturing, and sourcing is discussed; in this context, the impact of international standards and of the protection of intellectual property rights is considered. Third, critical success factors for new entrants into the global electronics marketplace are identified, including a discussion of selected elements of strategy at national and enterprise levels.

Characteristics of the Global Electronics Industry

For the past two decades, worldwide production in the electronics sector has grown faster than in any other industrial sector. This has been associated with rising demand for existing products, introduction of new products, opening of new markets, and increasing penetration of electronics throughout the rest of the economy. By 1987, the value of electronic equipment and components shipped worldwide accounted for 18 percent of all manufactured goods, some $470 billion out of a total of $2.6 trillion. In 1991, shipments were estimated at $635 billion, of which the computer subsection accounted for about $200 billion, communications $75 billion, semiconductors $45 billion, and consumer electronics $64 billion. Growth is expected to continue through the end of this century, at a rate of 10 to 12 percent per

annum. By the year 2000, the electronics sector is expected to reach annual production levels of about $2 trillion.

Impact on Other Industries

Electronics has profound effects on all other industrial sectors. For example, in 1988, electronics amounted to some 3 percent of an automobile's cost, a figure predicted to grow to 13 percent by 1997 and to 17 percent by

2000. Major growth areas include engine and transmission controls, automatic braking systems, instrumentation, and sound systems. Worldwide automobile output was 31.5 million vehicles in 1990, projected to grow to 35.5 million in 1995. Likewise, avionics is taking an ever increasing share of total expenditures in civilian and miliary aviation. It currently accounts for almost 20 percent of the cost of civilian aircraft, and this proportion is expected to grow further. The competition among Boeing, McDonnell Douglas, Airbus, and Mitsubishi (among others) for civilian aircraft airframes is increasingly a struggle for market share in avionics.

Technological advances in electronics also help upgrade traditional industries such as textiles, steel machine tools, and food processing. For example, in machinery products the advent of electronic controls has changed the design and manufacture of conventional equipment, enabling the development of totally new machine tools, leading to dramatic changes in the entire machine tool industry and its infrastructure over the last decade.

More generally, electronics has a major impact on quality and on labor productivity in most industrial sectors, including the electronics industry itself.

Interdependencies Among Subsectors

Traditionally, five subsectors of electronics are distinguished: telecommunications, computers, industrial, consumer electronics, and semiconductors. Such classification, however, obscures the interdependencies among segments of the electronics industry. Specific enterprises and products shift easily among subsectors and all share common requisites for effective utility in the marketplace, as well as common design tools and manufacturing practices.

There is a great deal of synergy among developments in the different subsectors. For example, consumer electronics has benefitted from controls and software developed for computers, while consumer electronics contributed high volume manufacturing methods, graphics capabilities, and optical storage to the computer subsector. Telecommunications supplied networking technology to computers while receiving control and software methodologies. Computer architectures have also been applied to modem semiconductor device development, while computer−aided design (CAD) and computer−aided engineering (CAE) tools, backed by the computer subsector, have propelled the development of semiconductors, industrial electronics, and consumer electronics.

Growth as Systemic Change

Much of the growth in electronics reflects systemic change rather than substitution. The development of new generations of electronic products is inextricably interwoven with strategic changes in manufacturing, marketing, and service, contributing to increased interdependency among sub−sectors. The story of the development of the electronic typewriter provides a good example.

The electronic typewriter was initially developed as a direct replacement of the electric typewriter (Figure 2.1). The basic electronic typewriter was cheaper to produce, more reliable, and had better service characteristics than the previous electromechanical machine, but the essential functions remained unchanged.

However, the use of electronics made it possible to add features to the initial designs of the typewriter at a cost far below the perceived value of these functions to the user. Product differentiation was accomplished by the addition of new features, and the manufacturers achieved lower cost per function and larger profit margins, especially during the early product introduction period.

The growing demand for electronic typewriters had profound effects on the manufacturing resources employed. The product was redesigned for high speed manufacture, not only to reduce costs, but even more importantly, to improve product reliability and reduce service costs. Items with longer lead times, such as manufacturing tooling for keyboards, cases, and cabinetry, could remain relatively constant through a number of product changes. Product differentiation was easily accomplished by changing printed circuit board assembly during manufacturing.

These office machines were then sold through expanded and new distribution channels. For distribution, the electronic typewriter was treated as a packaged goods product, in which the location of the plant became important in terms of shipping cost relative to the total value of the product. Service was no longer the province of skilled techni−

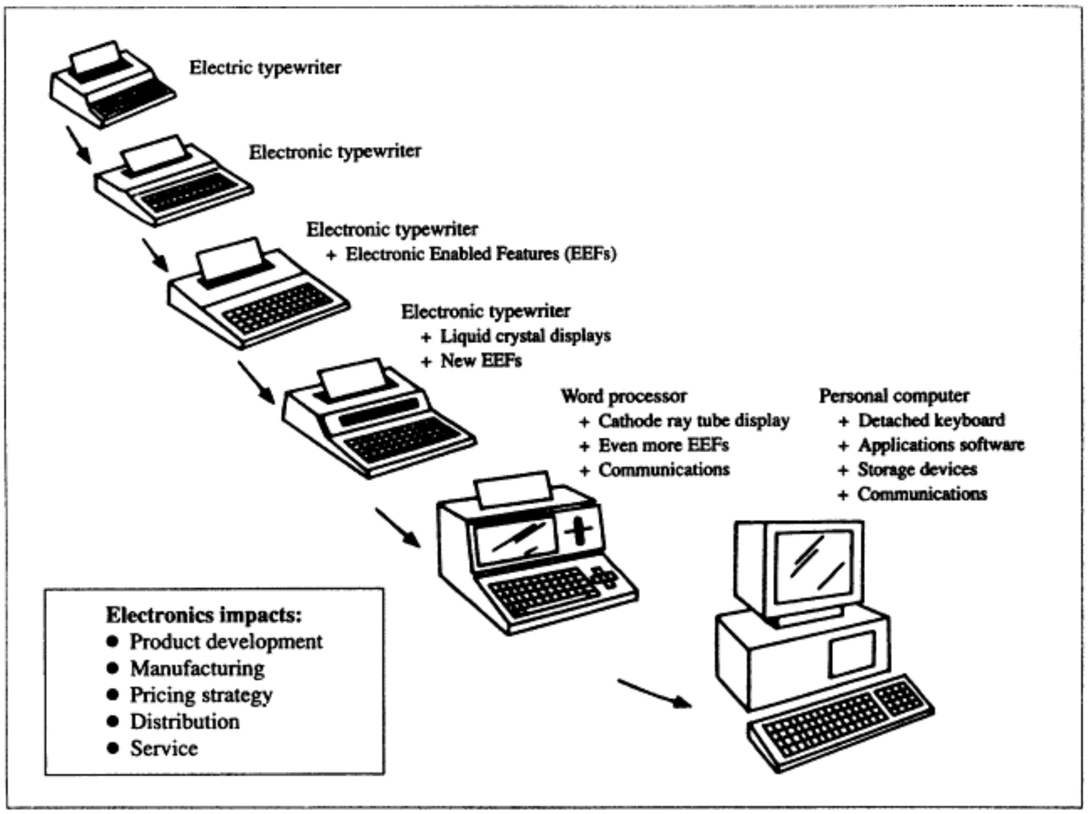

Figure 2.1
Evolution of the Typewriter as an Example of Product Differentiation by Electronics

cians, but became a relatively simple substitution of failed disposable modules. Warehousing and spare part disposition patterns also changed.

Electronics subsequently enabled the addition of more advanced features such as spell correction, justification of margins, and complex page layouts. Prior advances in liquid crystal displays (LCDs), driven by the watch and automobile industries, made them cheaper and easier to incorporate in design. LCDs and memory correction features were relatively easy to add to new models. In each case, the product development cycle from design to manufacture was measured in months instead of years. For limited periods of time, product differentiation on the basis of added features allowed competitive advantage with price premiums.

Through the electronic technologies of computers and telecommunications, communications capability was then added that allowed electronic typewriters to communicate with each other through telephone lines. This development gave rise to another line of products and another case of product differentiation. The next move was to full−page displays. However, consumers initially did not respond well to this feature. Thus, development was slowed down by market acceptance, rather than by technology constraints or higher cost. The evolution of the electronic typewriter into present day word processing machines, eventually merging with personal computers, was a consequence of the development of hardware and software capabilities.

As the electronic typewriter evolved, the modem electronics manufacturing plan structure remained intact. Flexible manufacturing and design techniques allowed easy model changeovers, and permitted the assembly of multiple models on a single line. Today, with the advent of digital electronics and advances in manufacturing methods and automation, a single automated electronics plant can handle hundreds of different board configurations per month. Production economies of

scale have been profoundly altered. Then too, the utility of electronic manufacturing plants has been broadened and manufacturing capability has been decentralized to serve market centers worldwide.

Opportunities for New Entrants

Changing technology, manufacturing processes, and market requirements, along with the redistribution of cost elements for various electronics products, are all significantly changing worldwide sourcing of electronics. The new parameters open opportunities for developing countries, while reducing the viability of traditional options. These same technologies affect the process of design itself and, in turn, radically alter manufacturing practices. Distribution and service patterns are also evolving in response to changes in the market and the continuous application of new technologies. Accordingly, increased demand for better trained and more highly skilled workers, with concomitant reduction in the need for unskilled labor, has occurred. Such rapid change can be achieved only by striving for flexible sector strategies and introducing supporting public policies which can accommodate change and manage local failures.

In the 1970s and early 1980s, consumer electronics was a relatively easy market entry point for new plants. Consumer products were relatively cheap to produce and could be of variable or even substandard quality. Performance expectations of consumers were not high. Today, consumer electronics has shifted to more complex systems, like color TV and CD players, demanding higher standards of quality and reliability. Differences in sophistication and quality between consumer electronics and other electronic subsectors have vanished, and the quality requirements of high−end and low−end products are converging. In most cases, automated facilities are required to produce the products. Manufacturing plants for consumer electronics are no longer sharply distinguishable from plants producing industrial electronics. Even with this caveat in mind, the consumer electronics sector remains a very attractive entry point for developing countries' overall electronics strategy, but the new requirements for modern consumer electronics must be comprehended.

Forecast for Change

The electronics industry will continue to undergo dramatic changes during the 1990s and these changes will have an impact on the ability of firms and countries to compete in the global market. Market development will continue to be driven in large part by technological innovation, especially in the areas of semiconductors and software. While modern manufacturing capabilities and the capital to invest in continuous improvements in manufacturing processes will remain important, so too will the development of a strong relationship between the manufacturing and service entities of a company. Finally, smart sourcing strategies, attention to evolving international standards, and the development of strategic alliances will affect the competitiveness of firms and countries in international electronics. These factors are discussed in greater detail in this section.

Technology

Market development is closely interwoven with technological innovation. In particular, some analysts believe that the electronics industry is driven primarily by developments in semiconductors, and that silicon semiconductor circuits will continue to be the premier enabler of advances in industrial, commercial and consumer electronics into the next century. Although this is an oversimplification, it provides a useful starting point for assessing future trends.

Semiconductors

The size and cost of semiconductor devices have been rapidly decreasing, with little or no tradeoffs in significant parameters. The reduction in device line widths from 5 to 0.8 microns occurred in 20 years; so too did the movement from 3−inch to 8−inch diameter silicon wafers. The economic manufacture of more complex, more energy efficient, and less costly devices has become possible despite the more complex equipment and plant required, because more functions can be packed together. Intense competition has resulted in lower costs being quickly passed on to the users as lower prices.

For the past 15 years, the cost per bit of memory devices produced worldwide has been declining at the rate of about 30 percent each year. Over the past 20 years, total memory capability in bits has doubled year after year. Commercially available commodity dynamic random access memory devices (DRAMs) have successfully increased in capacity from 16 kilobits (Kbit) to 64 Kbit to 256 Kbit to 1 megabit (Mbit) over a 20−year period. In 1991, 4−Mbit DRAMs were in volume commercial production; it is expected that in 1993 16−Mbit memory devices will be produced in volume for the open market. In 1991, IBM announced limited production of a 16−Mbit DRAM, with volume captive production achieved in 1992. This represents a three−year interval for a four−fold increase in individual memory device capacity, down from an ear−

lier five−year cycle. Within this same time span, the cost per logic function has declined over 20 percent Per year. As in the case of memory devices, the functional complexity Per logic device has risen markedly, resulting in collateral major cost savings at both device and system levels.

The availability of ever cheaper memory and logic has generated an application revolution that affects every element of the electronics sector and the products and services of which electronic parts and systems are elements. There is a continuing substitution of smaller, cheaper electronic devices for more expensive ones, replacement of electromechanical devices with less expensive electronic components, miniaturization of equipment, a far broader functionality, and a corresponding expansion of industrial and consumer applications. In many cases, the direct substitution phase is being superseded by a systems revolution in both product design and in the nature of applications. Changes in the product design and manufacturing cycle contribute to shorter product life cycles and more rapid introduction of products into the marketplace. Newer electronic technologies and manufacturing methods are enabling shorter development times, faster time to market, more competitive prices, and improved quality characteristics. As noted in the earlier example of the electronic typewriter, there is ongoing change in the nature of distribution processes as well as in service strategies for these products. Electronics now allows product innovation and differentiation at a level and at a speed never before possible, an important factor in global market capture.

Software

Electronics hardware development has been accompanied by increasing relative importance of software, especially in computers and telecommunications. Today, the ratio of hardware to software cost in computers is 1:1, compared to 5:1 in 1970. Whereas the electronics industry as a whole is growing at 10 to 12 percent per annum, software production worldwide is projected to grow at 30 percent per annum for the rest of the century.

These figures, however, reflect not only increasing use of software but also gradual productivity gains in software development. Whereas hardware productivity as measured by functionality per unit of cost has grown dramatically, and computer processing capacity has increased about 40 percent annually since 1960, during the same period the increase in programming output per person−hour was only about 5 percent per year. Many of the technologies and organizational methods of hardware development are also being used to lower the cost of software. These techniques include standardization of software tools, procedures and specifications to facilitate partitioning of the work, and the modular design of software to permit the reuse of major blocks of code. The application of higher level languages, improved process management, and enhanced tool support have made an impact. However, no fundamental breakthroughs in code generation are in sight.

Design and Manufacturing Tools

CAD and CAE are being used to an increasing extent in the development of new devices, as well as in the design of circuit boards, subsystems, and even whole systems. The design process is thus evolving, making manufacture easier, faster, and capable of ever more complex structures. However, this change underscores the requirement for close teamwork between engineering, manufacturing, and sourcing functions. The traditional sequence of design and prototyping of products by an engineering organization, passage to a manufacturing organization for implementation and production, with sourcing of appropriate material, components, and subassemblies from suppliers, is no longer effective. Engineering and manufacturing must now work together almost from the inception of the product development cycle. The producer must also bring in key suppliers to participate in the development process. The increased teamwork required among these activities has had profound organizational implications.

As the design process changes, manufacturing processes and sourcing strategies are also changing. Product life cycles, formerly 5 to 15 years, are down to three years for instrumentation, one to one and a half years for computer products, and one year for consumer electronics. The life of a new microprocessor is now four years, and of an application−specific integrated circuit (ASIC), just over one year. Microprocessors and ASICs are both the drivers and victims of the shrinking product life cycle.

Trends in system architecture emphasizing hierarchical techniques are emerging. The power of the individual microcomputer is growing drastically and the definitions of microcomputers, minicomputers, and mainframe computers are becoming blurred. Parallel processing techniques are being applied to minicomputers and mainframe computers. On the macro level, networks and distributed computing technologies are being introduced. As the overall cost of hardware keeps falling and the power of the microcomputer and workstation keep increasing, these products are becoming more ubiquitous and more useful. Network distributed workstations are moving into traditional mainframe markets. As CAD tools proliferate, they will increasingly be used by engineers and technicians alike, necessitating that a greater number of workers receive higher levels of education and specialized training.

Common databases are being established to merge engineering and design data with manufacturing, service, and distribution data, on a modular basis. However, there will not be sweeping introductions of these tools, since they must develop over time as the various components of the enterprise are reconfigured in an orderly fashion to utilize the new management information systems (MIS). This is analogous to the incorporation of computer integrated manufacturing (CIM) processes into the enterprise.

ASIC—An Example of Converging Technologies

The development of ASICs was the result of the confluence of these forces and technological advances in the design process, greater utilization of CAD, CAE, and CAM tools, and the increased use of flexible manufacturing techniques. The term ASIC applies to a class of microelectronic devices whose characteristics can be specified by the user. In fact, in many cases, the actual design is performed by the user.

Users of ASICs are supplied with a library of functions and an appropriate set of design tools. This puts product differentiation back into the hands of equipment producers, contrasting sharply with the former practice of using standard components which are produced in very large volume by merchant manufacturers. Currently, for every $1.00 invested in ASICs, the corresponding system unit manufacturing cost is reduced by $3.50, a sizable impact. In 1991, the sales of board−level ASIC products were approximately $2.5 billion; by 1995, ASIC sales are projected to grow to $5.0 billion.

ASIC components are used in conjunction with mass−produced memory, microprocessors, and logic. For a variety of design, packaging, functionality, and productivity reasons, ASICs are likely to pervade all subsectors of the electronics industry over the next decade. The value of ASICs are expected to rise to some 30 percent of the total value of devices produced, with ASIC market value projected to grow 20 percent per year over the next five years.

At Motorola, National, Fujitsu, and other com−parties, ASIC tools are being used expressly for internal microprocessor development. The biggest economic gain in their use by these particular com−parties is the reduction in time to market for new designs.

When ASICs were initially introduced, it was believed that this development would give rise to a large number of stable, small enterprises, since the actual number of devices of any particular type would be very small compared with the high volumes that a merchant manufacturer enjoys. It now appears that this is not the case. The acquisition of integrated CAD tool libraries, the high cost of the manufacturing, testing, and packaging facilities, and the required modification of modern semiconductor plant manufacturing methods to process large numbers of short−run designs will eventually enhance the effectiveness of the plant investment by the major semiconductor producers. The required overall cost, utilization structure, and movement of major semiconductor firms indicates that large merchant integrated circuit producers worldwide will capture the major share of the ASIC market. Smaller specialty ASIC vendors (some 100 in number) are being squeezed. Some are becoming more like niche tool suppliers, with designs as an adjunct. In 1992, an estimated 75 percent of the worldwide market was controlled by only 20 suppliers.

ASIC technology's greater emphasis on customer service means that design centers must be established close to or within the served enterprises. The designs are prototyped and subsequently manufactured by various device foundries around the world. This will allow training of the local users in the use of ASICs by the producers, permeating and changing the design processes for electronics−based products within these local enterprises. The local enterprise is assured of obtaining the latest in tools and structures, test equipment and packaging methods, as well as rapid turn−around for both prototypes and production runs. A new level of teamwork between the component and product manufacturer is evolving.

Manufacturing

Conventional wisdom in the 1980s suggested that an industrial society would move toward a post−industrial service economy, continuing an evolution from agriculture to manufacturing to services. The proportion of people employed has in fact declined in agriculture and manufacturing and risen in services. Modern electronics, however, has heightened the need for strong relationships between manufacturing and services in order for many of the new service functions to be performed efficiently. Manufacturing capabilities and strengths thus continue to be required for a healthy economy, even in post−industrial societies.

Modern electronics manufacturing is increasingly capital intensive. The move toward 'mote flexible computer−aided manufacturing (CAM) is restoring the ability of the industrialized countries to compete in electronics manufacturing. However, the increased utilization of CAM is not driven primarily by the desire to reduce direct labor, but by the necessity in the modern electronics sector to produce new products quickly, flexibly, and in high volumes. CAM improves product differentiation and reduces the time to market. In a given automated electronics plant, the combination of direct labor costs and capital employed per unit of output is now less than that of a manual or semi−automated plant. This is likely to make industrialized countries more competitive in manufacturing and force reconsideration of new balances and new strategies among the developing countries. On the basis of technological factors alone, there is good possibility of a reversal in competitive advantage, as capital intensive flexible automation is used more and more in industrialized countries. Market access, supplier methods, and material and labor sources are mediating factors. Over the past 20 years there has been an increase in manufacturing capability of some 600 percent in Japan, 80 percent in Europe, and 50 percent in the United States. This has happened even when the major global shifts to the Asian countries occurred, with their own dramatic gains in manufacturing capability.

Quality, cost, and delivery have been the three primary drivers in the operation of a manufacturing facility. In the past, especially in electronics, trade−offs among them have been possible in order to enhance competitiveness. Low cost was traded for poorer quality and longer delivery times in lower and middle level consumer electronics. However, this has changed. The use of automation methods in the factory, properly applied, improves product quality. Labor cost reductions are a concomitant benefit rather than the primary objective. Control of the automated process elements allows for rapid turnaround time and quick delivery. For many products, the only way to achieve quality and performance is by automated manufacturing techniques.

Conventional learning curve criteria for an electronics product manufactured in such plants are significantly different from the past. Far greater product design flexibility and quality improvement can be achieved through automated manufacturing methods, coupled with the use of CAD/CAM tools. Introducing CIM technologies into the automated plant allows more effective control of factory processes and significant reductions in inventory costs by balancing distribution and service costs. These methods are being introduced gradually in existing electronic manufacturing operations. Making these methods effective involves both organizational and material changes.

The rise of automation and the increasing application of CAD and CAM techniques to meet the requirements of the competitive global electronics marketplace reinforces the conclusion that two tiers of quality within the same manufacturing operation cannot be tolerated. The nature of the manufacturing processes, the training and discipline required, and the ability to achieve economies of scale with a mix of products preclude such an option. A uniform, world class quality standard is required for components, assemblies, and finished products. These considerations apply to all countries, including the former Eastern−bloc countries entering the European trade arena. It would be incorrect to assume that these quality discussions only apply to the newly industrializing countries with Organization for Economic Cooperation and Development (OECD) market aspirations.

Major new packaging technologies are being introduced into the factory. Fixed reel automatic insertion equipment is being superseded by flexible, easily programmed device placement equipment for the manufacture of board products, a change which is essential for product differentiation. The push to increase product functionality, reduce physical size, and drive costs down is realized by ever improving packaging technologies.

The availability of CAD, CAE, and CAM tools allows results from the various manufacturing stations on the shop floor to be fed back directly into process control. It also permits the incorporation of field service results into the manufacturing lines to permit corrective actions to be rapidly implemented to improve product quality. This changes the requirements in the structure and operation of the enterprise and requires more extensive personnel training. Finally, and most intriguingly, it promises to change the distribution of training responsibilities between the enterprise and the school system.

Sourcing

Electronic products today are characterized by ever shorter product life cycles. Technological and geopolitical considerations are changing worldwide sourcing patterns and the economic determinants of plant placement. An effective strategy of global plant placement requires the dose proximity of manufacturing, marketing, sales, and service support serving each region. This has put new pressures and requirements on local regions if they wish to remain or become attractive sites for pro−

duction. Increasingly, products are being customized to meet specific customer needs responsively, with dramatically reduced development−to−market cycles. The regional design and service centers, as well as in−plant design and service centers, have become more closely linked.

Today's design process involves close teamwork among engineering, manufacturing, and principal suppliers from start to finish. As regional manufacturing sites spread worldwide, they will include technology−driven engineering activities, with the requirement for local sourcing of components of quality commensurate with that of the end product. A local components industry with world class quality standards and performance is a vital element of a national electronics strategy.

International Standards

International standards play an important role, both in developing export market capabilities and in helping firms determine objectives and formulate follow−up strategies for the manufacture and sourcing of high−quality products. For industrialized countries, standards also provide discipline and a "window on the world" to guide product strategies and the timing of product introductions. Standards can also help national electronics authorities to provide an effective product/subsector focus and eliminate unnecessary duplication of effort. Standards are also an obvious necessity in developing global sourcing strategies.

The following examples of international standardization demonstrate well their commercial and technological importance. The telecommunications industry and the computer industry are very dependent on open system interconnects and open network architectures based on a set of common standards. Digital switching costs less to produce than the corresponding electromechanical devices, requires less maintenance, and allows extensive additional services to be offered via software and modular electronic hardware. In turn, codified international standards are necessary for Integrated Services Digital Networks (ISDN), integrating image, voice, and data services, to become operational.

The mass storage "write once, read many times" CD−ROM optical storage system was technologically and commercially feasible several years ago. Both Sony and Philips were in a position to produce these products for the market, but there were no uniform international standards. Neither wanted a repeat of the ill−fated VHS/Beta/V2000 format struggle which occurred in VCRs a number of years earlier. Consequently, international standards for CD−ROMs were agreed to and ten manufacturers are now producing for the emerging market. Until then, the absence of standards precluded worldwide marketing acceptance, even though technologically, CD−ROMs were out of the embryonic phase and should have been in their growth phase much earlier.

Standards also affect the components side of the electronics sector. Standard packages for many active and passive devices have allowed the interchangeable use of these elements on a worldwide basis and are a very necessary part of any global sourcing strategy. Surface mounted devices (SMDs) and their pick−and−place equipment have been a battleground for standards among the various producers. The resolution of these disputes and the conformance of products to agreed standards ultimately accelerated the application of important packaging and automated assembly technology. Effective standards have also significantly affected the suppliers of SMD components, encouraging the entry of new producers into the marketplace.

The introduction of digital, high definition television (HDTV) products will have a major impact on consumer electronics and on the suppliers of components and assemblies. HDTV production has been stalled because of a dispute over standards and systems among key players representing competing regions and countries. The conflict will continue until a set of international standards is established, since it is clear that no one company or region can unilaterally impose their will globally or, conversely, restrict their approach in their own market, and still remain competitive.

At one time, Western Europe considered international standards in the electronics field as anathema, much to the detriment of their electronic sector growth. Western Europe accounts for some 33 percent of world electronics consumption, but only 19 percent of global output. In the past, the use of local standards as *de facto* national trade barriers, coupled with selective local government procurement policies, prevented individual local enterprises from developing suitable economies of scale to participate in the global market. The subsequent merger of many of these smaller local enterprises into larger national ones operating with the support of government subsidies and incentives still did not strengthen international competitiveness or improve economies of scale. Recently Western European nations have changed their approach. The European Community (EC), European Free Trade Area (EFTA), and European Telecom−

munications Standards Institute (ETSI) are working toward adoption of open system interconnects and regional standards, to better position European companies in the global marketplace. Standard setting is now a major component of the efforts to develop a single European market.

In the computer area, a nation's adoption of *de facto* international standard operating systems in microcomputers facilitates the incorporation of new technologies and new application software packages and helps shape product strategies. This is especially important for late entrants into the global arena. Local enterprises using technologies and indigenous specifications that differ from *de facto* international standards often lag behind those technologies in the global marketplace. These companies are often precluded from taking advantage of improvements which occur elsewhere in sectors meeting international standards. Brazil has had such an experience in the information sector in the 1980s. India's similarly closed approach prevented its electronics companies from becoming global competitors.

The 21−company consortium in the United States for the Advanced Computer Environment is a standards−setting effort to allow market penetration against entrenched producers. The target is the market dominance enjoyed by IBM and Sun Microsystems proprietary systems in high−end reduced instruction set computer (RISC) workstations. To wring market share from IBM and Sun Microsystems, the consortium seeks to create a new standards−oriented system architecture in 1992, followed by the introduction of individual competitive workstations by various competitors. A similar standards−setting effort, the Open Systems Foundation, has been launched by a number of international computer manufacturers. This latter effort, however, is foundering, owing to the defection of key members.

Intellectual Property Rights

Because of strong competition from the NICs, increasing costs, and the shortening of product development cycles, during the past decade, the advanced industrialized countries have waged a far more vigorous defense of their intellectual property rights concerning processes, designs, and equipment. This has major implications for the newly industrializing countries in their efforts to participate in the global electronics market.

For example, in the case of software, an emerging legal framework grants computer programs copyright protection as literary works. It places restrictions on the reverse engineering of copyrighted computer programs. Copyright protection and the prohibition against reverse engineering is enjoyed under U.S., Japanese, British, French, German, and Spanish law. These laws help protect these countries against imports of reverse−engineered software from other parts of the world.

Some global companies are exacting significant royalties for the use of many of their early basic patents in the semiconductor arena. Texas Instrument's (TI) strong patent portfolio and the creation of a special patent court system in the United States to deal with ownership issues has aided TI's business strategy of maximizing royalty collection. In fact, TI treats intellectual property as a profit center, broadening the coverage to include not only a broad range of semiconductor products and processes but also computer systems. In 1987, TI received some $191 million in royalties from eight semiconductor companies in Japan and one in the Republic of Korea for use of these basic patents in production of commodity memory devices. In 1991, TI collected $256 million in worldwide patent royalties, up from $172 million in 1990. Semiconductor patents accounted for 80 to 90 percent of this revenue. This all serves to help fund TI's R&D and maintain their global competitiveness.

In contrast to their previous less activist stance, IBM has also taken measures to protect its intellectual property position in computer hardware and software. After a hard fought arbitration action in 1987, IBM obtained major payments from Fujitsu for the use of IBM technology for mainframe computer operating system software. More recently, Hitachi and IBM have come to terms over use of IBM mainframe technology, again after vigorous prosecution by IBM. These efforts have been successfully extended by IBM to their components and personal computer arenas.

The response of established companies to new entrants has thus been to defend their position through the vigorous protection of intellectual property rights. Consequently, reverse engineering electronics products or processes without compensating the owners of the intellectual property rights has become more difficult. This provides clear incentive for developing strategic alliances.

Development Strategies for Late Entrants

For efforts to develop a modern electronics industry to succeed, they must achieve several strategic goals: progressing rapidly from technology to

product, production, and distribution using efficient market channels; achieving internationally competitive export prices and quality standards with sustainable internal cost structures; and anticipating and meeting customer requirements.

Critical Success Factors

The extent to which a country or firm can achieve these strategic objectives depends on a large number of factors, with a limited number of critical importance. Critical success factors can be identified by examining the nature of technological changes in electronics, the emerging global patterns and distribution of producers and consumers, the changes in key players, and case studies of various country experiences. The set of critical success factors is of value to developing countries in assessing the relative merits of alternative approaches to building up a modern electronics industry.

Eight critical success factors for building a modern electronics industry can be highlighted:

government policies and strategies that support electronics sector growth and competitiveness;

education and training programs to build up the base of human resources;

national industrial and quality assurance infrastructure to support enterprises;

export marketing, distribution, and sourcing networks to support the emerging electronics industry;

economies of scale, with cost, quality, and productivity levels meeting international benchmark levels;

foreign strategic alliances to achieve effective technology transfer and engender sufficient foreign development investments;

enhanced shop floor management; and

flexibility in the public and private sector institutions, to adapt to changes in markets and technologies.

This set of critical success factors can be used as a guide to review alternative development strategies for sector development at both the national and enterprise levels. Some such elements are briefly discussed below.

Elements of National Strategy

Developing countries and NICs face the challenge of creating an environment that encourages more efficient operation of existing and new enterprises. Macroeconomic, trade, investment, and industrial policies of government affect the prospects of building up a competitive electronics sector. National policies must also take into account possible international responses. In particular, developed countries have stepped up their protection of intellectual property rights in response to growing import penetration and loss of global market share. Developing countries may wish to accelerate the creation of strategic alliances to ameliorate the added cost of technology acquisition, as well as create and enforce their own national patent and copyright laws.

Human Resources Developments

One important area for public policy is human resources development. A skilled workforce is vital to development of the electronics industry. The demand for unskilled labor will decline as competition drives technological and manufacturing advances. On the other hand, the demand for trained workers will grow even as productivity increases, because of the accompanying growth of the electronics sector and collateral industrial sectors. As a consequence, electronics will make major demands on developing countries to improve and expand their education systems.

As the electronics sector grows, there is increasing need for scientists, graduate engineers, and technicians. Enterprises require skills in the sciences, electronics and computer engineering, design and process engineering, industrial and manufacturing engineering, and business and factory management. Often, university and college curricula need to be revised to meet the sector's needs in a focused manner. A new education process will be required to train the technicians and the skilled factory workers handling the tools of the next decade. Vocational schools with specialized curricula may need to be established. A far greater budget for in−plant training with experienced instructors will also be needed.

It is worth reiterating that technician training is not a function of the university, but rather of trade and training institutes. An interesting model is the vocational training establishments in Singapore. These include schools in mechanical, electromechanical, electronics, and software disciplines, focusing upon enterprise practices and needs. They have developed training programs and techniques, which over the years have proven to be very effective in turning out high quality, well−trained technicians to meet expanding requirements of the electronics sector.

Industrial Infrastructure

Another key area of public policy concerns the growth of a strong infrastructure of supplier firms, standards, and quality assurance. No country has ever become a global player in the electronics market without a strong infrastructure of suppliers. Likewise, standards

and certification programs are required for both passive and active components as well as key products such as printed circuit boards. These need to be overseen by certification agencies that are credible, operate in a timely fashion, and have the power to certify. Such standards and quality requirements can also be used as metrics to help determine the allocation of funds if means other than market forces are appropriate. The creation and utilization of this type of authority is vital for the development of an electronics components industry.

Given both the nature of a modern electronics production facility and the nature of global sourcing, strong supplier networks are extremely important. Starting with the design process itself, the producer of electronics goods and its suppliers must cooperate closely. The achievement of quality, cost, and delivery as well as just−in−time (JIT) manufacturing methodologies require a close coupling between the producer and its suppliers.

Supplier networks are absent in most developing countries. Lack of supplier networks deprives the countries of a powerful tool for internal transfer of methods and skills for quality control, inventory control, production planning, and management information. This affects not only the viability of the individual producing enterprise, but also the collateral supply network. Lack of supplier networks spawns an over−reliance on foreign components and subassemblies, fragments the local components industry, and injures the country's export posture. Developing customer−supplier networks should be a top near−term priority of policy makers.

Manufacturing technology centers are another useful component of infrastructure development. They address key elements of manufacturing processes and their services are tailored to the needs of local enterprises. Technology centers serve both as data banks and providers of support functions.

Elements of Enterprise Strategy

Enterprise managers are understandably wary of how and under what conditions their technologies are transferred to other enterprises. In most cases, enterprises allow others to share technologies to some extent. The rate of technological growth is far too rapid for any one enterprise to completely control its technology and exclude all others from its use. Rather, the objective of enterprise managers is to formulate technology arrangements with a perceived satisfactory return on their investment. The revenues accrued over time, in turn, facilitate future innovations for the parent enterprise. The merits of alternative arrangements differ among enterprises.

Technology arrangements among enterprises, and especially between firms in different countries, are only viable in the context of appropriate public policies. Any country attempting to enter the electronics industry usually must offer some combination of policies to attract suitable arrangement partners. These include (a) flexible profit repatriation, (b) satisfactory access to internal markets, (c) non−discriminatory access to domestic supplies and raw materials, energy, and labor, and (d) long−term participative partnerships which are truly of mutual benefit. Long−term relationships are important because technologies need to be upgraded over time. There should be sufficient retention of profits by the enterprises to facilitate self−renewal of their technologies.

Technology Acquisition and Development

The growth, profitability and even survival of any electronics enterprise hinges on successful arrangements to continuously acquire and develop technology. This is a dynamic process in which successive waves of technology, typically only a few years apart, go through overlapping life cycles from development to commercialization to obsolescence. As new products using the latest technologies reach the market, the next generation of technologies must already be under development.

The high cost of technology development and design, high up−front capital costs for manufacturing the next generations of products, and rapid pace of technological change, have compelled enterprises all over the world to establish alliances, partnerships, joint ventures and other collaborative arrangements among firms. There is an almost infinite variety of such arrangements. Competitors have entered into multi−firm consortia and bilateral arrangements, agreeing to cooperate at certain levels and to compete in others. Some arrangements involve technology exchanges while others enter joint technology programs. Still others have established jointly owned third−party enterprises. In some cases, one enterprise has absorbed or bought out the partner in the joint effort. Many times, the association has failed with losses incurred in time, capital, and business opportunity.

Arrangements for transfer of technology are closely linked to human resource development. Technology transfer to a relatively new player in the electronics industry generally involves the acquisition of equipment, written documentation, and personal interchange of know−how and training between the supplier and the recipient. The first two in the absence of the third actually consti−

tute incremental acquisition of productive capacity, not technology transfer. In many developing countries, however, investment in hardware is emphasized at the expense of the acquisition of know−how and in−depth training. For greatest effectiveness, a technology transfer arrangement should provide for a significant level of renewal of know−how transfer, as well as for in−plant training. The emphasis on hardware acquisition usually results in low utilization of acquired capabilities, correspondingly low production efficiencies, fewer lateral technology transfers to other enterprises, and limited likelihood of timely improvement of the acquired technology.

Domestic technology transfer among local firms enhances the utility of acquired foreign technologies. Domestic transfers may be accomplished through a variety of professional, vocational, and user group associations, cutting across sectoral lines. These groups provide effective forums for the communication of organized information, as well as a context for providing training programs that serve a number of enterprises. Although less structured, the mobility of technical personnel within and among enterprises, institutes, and universities is another effective means for information flow. Such lateral technology transfer methods increase the use and impact of technologies, even though competitive relationships between individual enterprises continue to exist. They provide flexibility and a base of knowledge for the sector, and reduce the risk that several companies will duplicate efforts to acquire the same technologies.

Strategic Alliances

Alliances among enterprises are made for a variety of reasons, including the ability to achieve regional market penetration, technology sharing and technology transfer, and manufacturing plan cost sharing. Despite significant cultural and strategic differences among enterprises, there is an overriding economic incentive to collaborate. The drive for globalization results in the requirement that alliances fund expanding technology requirements and reduce oversupply in markets which have weakened financial structures. In many cases, this leads to virtual vertical integration. In others, it allows market penetration in given regions. Few companies, or countries for that matter, choose to go it alone in all areas because it is no longer feasible to do so. The concept of national self−sufficiency has proven to be unrealistic. Illustrative examples from the United States, Europe, and Asia are mentioned below (several are discussed in more detail in later chapters).

Although U.S. electronics firms have been party to international strategic alliances since the 1960s, they were latecomers in forming alliances at home. Clarifications in national antitrust laws made in 1984 encouraged these arrangements. An early example, the Microelectronics and Computer Corporation is a consortium of 25 industrial firms; it deals with broad applied development programs in the computer, software, semiconductor packaging, and design subsectors.

The Semiconductor Research Corporation, a 34−member consortium working under the auspices of the Semiconductor Industry Association, funds directed university research of interest to enterprise, members; this has led to effective informal research networks, closer working relationships between enterprises and universities, and establishment of a number of strong teaching centers. While it has been innovative in developing novel means for multiple enterprise development programs, it has yet to fulfil its development promise to the consortium members.

SEMATECH is a consortium formed in 1987 of private U.S. manufacturing companies supported by matching government funds at a total annual funding of $200 million. It seeks to help overcome difficulties in effectively translating significant semiconductor technology innovations into commercial products, using DRAMs as the product vehicle for 1993 delivery. It is managed by private industry and has modified its aim toward strengthening the U.S. semiconductor process equipment industry and developing next−generation equipment to produce DRAMs. SEMATECH has provided significant benefits for a number of its members and the IC process equipment manufacturers. However, the total utility of its results in terms of the $1 billion investment to date is debatable.

Alliances are also on the rise in Europe and Asia. For example, the Joint European Submicron Silicon Initiative (JESSI), formed under the European Research Cooperation Agency (Eureka), seeks to foster future competitiveness of the industry by developing semiconductor processes for DRAMs with 0.35 micron line widths; an agreement with SEMATECH aims at developing related manufacturing equipment for 64−Mbit DRAM production. In a similar fashion, two rivals, NEC and AT&T, are collaborating to develop 0.35 micron CMOS to be manufactured separately by each company in 1995. A consortium of major Korean manufacturers was formed to produce 4−Mbit DRAMs. The German and Dutch governments established a joint program known as the Mega

Project with Siemens and Philips. The objective was to develop submicron technology fundamental to advanced memories. 1−Mbit SRAMs (Philips) and 4−Mbit DRAMs (Siemens) were the vehicles to be brought to full commercial manufacture. Although technological progress was achieved, the results were spotty. Siemens brought their product to commercial manufacturing competency; Philips dropped out of the commercial 1−MBit SRAM engagement.

Despite huge costs, good strategies include running parallel alternatives. While U.S. and European consortia in the DRAM area move along, many of their major industrial participants are hedging their bets. For example, Texas Instruments has a joint venture with Hitachi on DRAM development. IBM has one with Siemens for 64−Mbit DRAM development, targeted for introduction in the mid−90's. Motorola has an alliance with Toshiba. IBM has pursued a strategy to strengthen both the U.S. and European technology sectors in semiconductors. In a significant break with past practice, in mid−1991 they entered into an agreement with Siemens to manufacture 16−Mbit DRAM chips in a new plant outside of Paris. Half the production will be captive to IBM and the other half sold in the commercial market. IBM will supply the technology for their captive−produced DRAM, and they will jointly commercialize and manufacture on the open market. Most recently, IBM and Siemens have been joined by Toshiba in this DRAM consortium.

Consortia are not limited to semiconductors. Examples in other subsectors include the Japanese International Superconductivity Technology Center (ISTEC) and the Real−Time Operating Nucleus (TRON). Collateral skills generated by Japan's Institute for New Generation Computer Technology (ICOT), an otherwise unsuccessful alliance, are being contributed to a joint effort with Singapore's National Computer Board (NCB) to create the Japan−Singapore Artificial Intelligence Center in Singapore; the objective is to train Singaporeans in artificial intelligence, with Japan supplying hardware, software, and instructors.

An alternative to strategic alliances followed by Japan, Korea and more recently, Singapore, resorts to minority venture capital investments in small high technology electronics companies in the United States as vehicle for technology surveillance and transfer. This has included outright purchase and direct management of a number of these enterprises. Similarly, Nippon Steel made a significant investment in the large software house, Oracle, with a view to introducing Oracle products in the Asian market. To take another example, Fujitsu has taken over ICL of the United Kingdom; originally they were partners in a technical alliance, but when ICL became dependent on Fujitsu for a number of critical technologies as well as capital, Fujitsu purchased ICL.

Internal Organizations

The key to translating technological advances into product in a timely fashion involves a close coupling between engineering and manufacturing, and an effective operating environment within the plant. An overarching objective for firms in developing countries should be to achieve internationally competitive export pricing for electronic products as well as an internal cost structure that can sustain and support competitive international prices.

In order to achieve these objectives, a series of specific shop floor management steps must be taken. In developing countries, the electronics industry often suffers from inadequate plant and material layouts, poor testing of quality, shortfalls, insufficient provision for internal training, and inefficient plan improvement activities. Labor productivity and utilization are also low. On average, there is excessive attention to equipment acquisition to achieve incremental capacity requirements, while far less attention is given to enhancing elements of equipment and process utilization such as production efficiencies, inventory control, shop floor control, production planning, and supplier development.

Conclusion

The proof of the developing and newly industrialized countries' success in electronics industry will be their participation in the global arena with an array of high−quality electronics components, assemblies, and products, at internationally competitive prices with sustainable internal cost structures.

Becoming a global player in electronics industry can be daunting, yet there are a number of practical strategies that can pay off. Specific operational policy and infrastructure changes can have desired near− and intermediate−term effects without disrupting the existing political and economic environment. The challenge lies in converting these strategic goals into specific implementation plans to meet the objectives. The importance of continuous improvement in manufacturing processes, in training and retraining of front−line workers, and in sourcing decisions and inventory and management information systems, cannot be stressed enough.

One thing is clear. A seamless implementation strategy for developing and newly industrialized countries that is completely success−oriented is unworkable. The uncertainties are too many. Because developing countries must test alternative approaches with competitive players in a shifting global trade and technological environment, failure is both understandable and permissible. Strategies that are sensitive to the social and economic structure of these countries must be developed if winners are to emerge and losers are to be gracefully absorbed.

PART 1—
INDUSTRY CHARACTERISTICS

3—
Semiconductors

David Dahmen

The semiconductor industry is one of the major economic success stories of the last quarter century. Its growth has been phenomenal: the industry grew from a $100 million industry in the late 1950s to $58 billion in 1990, and is forecast to double to $105 billion in 1995. The development of new semiconductor products, manufacturing technologies, and applications has spawned revolutions in data processing, telecommunications, consumer electronics—in almost all sectors of the economy.

Intense competition within the industry, government intervention in both advanced and developing countries, great research and development (R&D) and capital requirements, and an extremely rapid rate of technological change pose real challenges to potential new entrants into the market, especially from developing economies. Once preeminent in the industry, U.S. companies lost market share in the 1980s as Japanese companies gained and overtook U.S. companies in some industry sectors. Intense competition prevails today.

This chapter focuses on characteristics of the industry. It compares the semiconductor industries and government policies in the United States and Japan, and touches on emerging situations in the Republic of Korea, Taiwan (China), and Europe. Appendix 3.1 gives data on the world's 21 largest semiconductor producer companies.

The Semiconductor Industry

The semiconductor industry is composed of three subsectors: semiconductor producers, semiconductor manufacturing equipment producers, and finished semiconductor distributors.

Semiconductor Producers

The semiconductor industry is one of the most R&D−intensive industries. For example, when compared with other U.S. industries, semiconductor−producing companies rank first in spending for R&D as a percentage of sales, outranking the drug, computer, aerospace, chemical and automotive industries. In the aggregate, over 13 percent of semiconductor producers' sales was plowed back into R&D in the U.S. industry in 1989. Certain companies spent even more: National Semiconductor spent 15 percent of sales on R&D, and Advanced Micro Devices spent 18 percent of sales on R&D. This trend is expected to continue, since there will be increasing emphasis on proprietary products and the manufacturing processes to make them.

The semiconductor industry is also capital intensive. Figure 3.1 shows the level of capital spending as a percentage of sales for the years 1975−93 (the figures for 1989−93 are projections). The increase in capital spending in 1983 and 1984 was in response to the nearly 50 percent increase in semiconductor sales during that period. By 1988, global capital spending in the semiconductor industry was $10 billion, an amount expected to double by 1992.

Given such high levels of R&D and capital spending, not surprisingly, the semiconductor industry is also characterized by extremely rapid rates of technological change, both in the design of products and in the processes required to produce them in quantity. For example, in the area of product design, the industry began shipping 1,000−bit dynamic random access memory (DRAM) devices

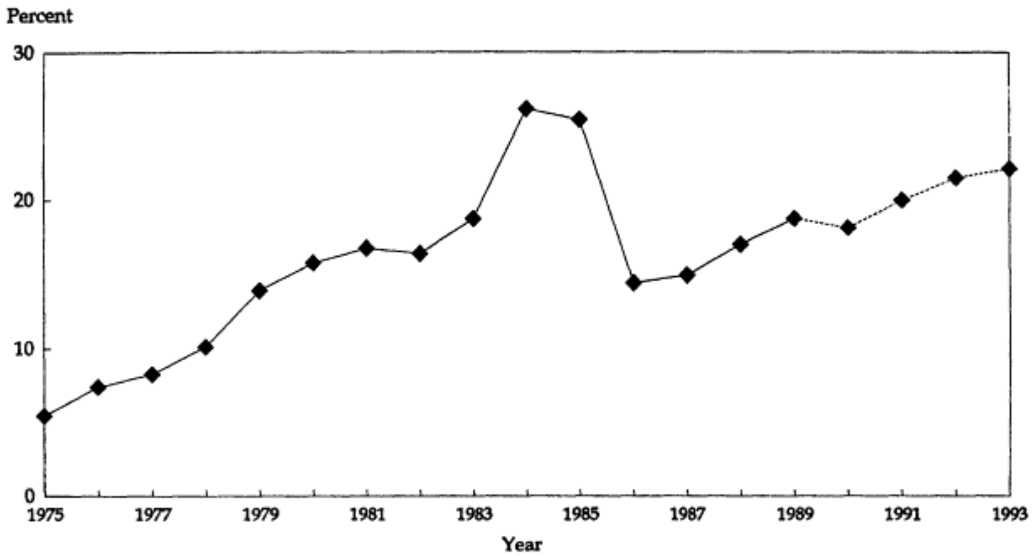

Figure 3.1
Capital Spending as a Percentage of Revenue, 1975−93
Source: Dataquest, October 1989.

in the early 1970s. The industry had increased the devices' DRAM to 16,000 bits by the end of the decade. By the mid−1980s, the industry was shipping 64,000 bits and 256,000 bits. Currently, the industry is shipping 4MB products, with 16MB to follow in the near future.

Advances in products have been possible only because of simultaneous advances in product design tools and production technologies. For example, most advanced products today are produced on six−inch wafers of 2 microns or less in clean room conditions that were not possible in the 1970s.

Given the level of competition in the industry, there should be no reduction in the rate of advancement in either process or product technology. One hundred and sixty companies now compete in the industry, including 90 from the United States, 30 from Japan, and 30 from Europe. Dozens of companies started up in the 1980s in the United States; two of the biggest companies (Advanced Micro Devices and Intel) did not even exist in 1970.

Intense competition has led to the shortening of product lead times for state−of−the−art products. Such times are frequently measured in weeks or months, and a new market leader will often emerge with each new generation of product (for example, DRAMs). Similarly, products have short life cycles. Figure 3.2 shows the life cycle of a typical semiconductor product.

The timing of product introduction is important. A company that introduces a product first, or early, has several advantages. It can be first with customer design−ins and qualification. Moving further down the learning curve first can also lower the cost structure in relation to competitors. The first companies to emerge with a product and gain market share also usually look forward to better profits and cash flows to fund the next generation of products.

Competition, intense R&D efforts, and the consequent rapid rate of technological change and commercialization have led to a decline in industry prices, which has both opened up new markets for applications and reduced the costs of equipment that use semiconductors. Average selling price (ASP) in the industry has gone down over time, but an even better measure of price decline is average price per function. For example, in 1960, the average selling price of a transistor was $5.00; by 1985 an integrated circuit (IC) containing 500,000 transistors sold for $5.00.

Larger wafers, smaller geometries, higher production volumes, and improved yields in the production process have all contributed to decline in price. Given the competitive pressures in the industry, there is every reason to believe that the

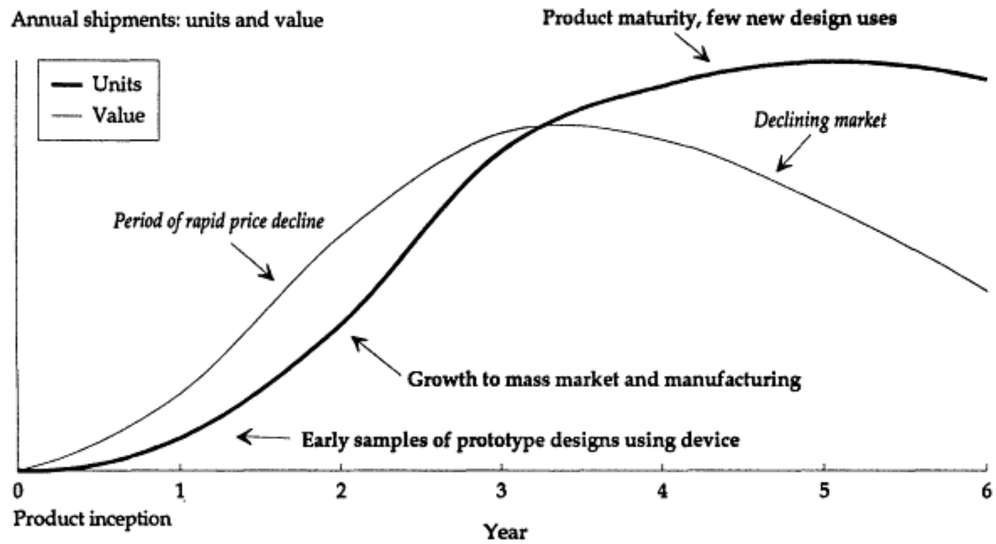

Figure 3.2
Typical Life Cycle of a Semiconductor Product
Source: Dataquest, December 1986.

cost per function will continue to decline in the future.

Finally, there have been dramatic swings in worldwide semiconductor consumption. Figure 3.3 shows yearly changes in consumption from 1970 to 1992, projected through 1995.

Such wide swings in an industry with a high fixed−cost structure led to severe financial repercussions, especially in 1985 and 1986 when capacity utilization rates fell below 50 percent in the United States and below 70 percent in Japan. The large reduction in capacity utilization came just as many companies were in the midst of or just completing major capital expenditures. This resulted in losses of hundreds of millions of dollars during a two−year period. Company finances were severely affected and thousands of people lost their jobs. Suppliers to the industry, such as producers of semiconductor production equipment, were hurt as well.

To address the swings in demand, many companies have begun to form closer relationships with their customers. This has taken the form of agreements to guarantee the delivery of products within certain lead times and thus reduce the problems of double and triple ordering that plagued the industry for many years. Given that major swings in demand and supply benefit no one in the industry, more arrangements of this type are likely in the future. It is also important to note that capacity utilization rates have varied depending on the specific product or technology involved (for example, bipolar, complementary metal oxide semiconductor [CMOS]). Currently, for example, the capacity utilization rate for leading edge CMOS facilities is higher than for many bipolar facilities.

The semiconductor industry continues to be characterized by a high rate of technological change, which has resulted in significant productivity gains. Capital costs for entry continue to be high, and continued competitiveness requires ongoing capital investment for producers of memory, microprocessor, and ASIC products. Overcapacity in memory products, reduced growth rates in consumer electronics, and competitive pressures in PC output all contributed to disappointing production figures in 1991−92. Overcapacity in memory production capability, coupled with sharp competition among Japanese and Korean producers, also led to price erosion. Due to these technological and economic factors, cost per function has dropped across the board in the semiconductor industry and producers continue to see erosion in their profit margins.

Viewing these developments as cyclical in nature, the semiconductor industry responded by reducing capital expenditures for both plant and

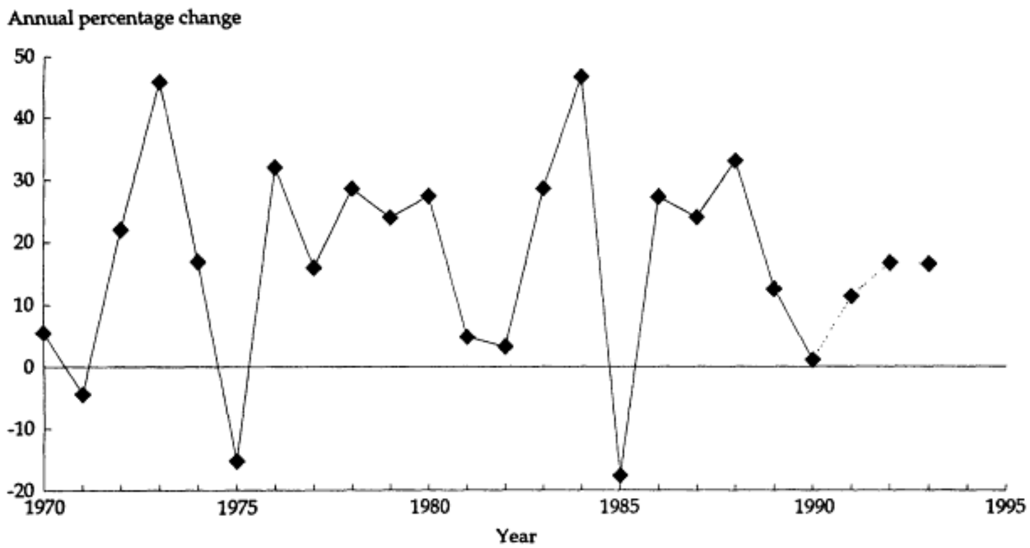

Figure 3.3
Change in World Semiconductor Consumption, 1970−95
Source: Dataquest, May 1991.

equipment in 1992. In the production of logic and ASIC devices, the rise of regional fabrication lines and more effective design tools have made it easier for system producers and device suppliers to respond quickly and economically.

New entrants into the semiconductor market face tough constraints. Strategic alliances are usually necessary in order to obtain technology and manufacturing capabilities as well as foreign market access. The significant capital investment required for memory production, coupled with sharp competition among existing producers, makes entry into this arena extremely difficult.

Semiconductor Manufacturing Equipment Producers

The semiconductor manufacturing process consists of three steps: wafer fabrication processing (commonly called the "front end" of the production process), testing, and assembly (the "back end" of the process).

In 1991, worldwide sales for semiconductor equipment producers was approximately $10 billion. Wafer fabrication equipment accounts for 65 percent of sales, test equipment for 25 percent, and assembly equipment for 10 percent. From the late 1970s until the mid−1980s, the industry grew at a compound annual growth rate of more than 20 percent per year. Following a major reduction in capital spending by semiconductor producers in response to slack global market demand for semiconductors, the semiconductor manufacturing equipment industry experienced a severe recession. Many firms were forced to scale back their operations, and others went out of business. Today the semiconductor equipment industry continues to undergo consolidation as a result of demand cyclicality and R&D spending levels. The formation of SEMATECH in the United States was partly an effort to assist this segment of the semiconductor industry.

Like semiconductor producers, semiconductor manufacturing equipment companies are also R&D intensive. R&D spending was prompted by advances in device−making technology. The number of transistors per semiconductor has increased, as well as the line−width geometries in new facilities. Wafers have grown from 4 to 6 inches within only a few years, and some companies are operating at 8 inches. The need for automation has increased to improve wafer fabrication yields. The need to assemble semiconductor devices with increasing pin counts has also been a spur to change in the manufacturing equipment industry. Finally, testing requirements have grown as semiconductors have become more complex.

The semiconductor manufacturing equipment industry in the United States has more than 1,000 firms, most of them with sales of between $1 million and $10 million per year. Close to half of these firms were established after 1970. Many of the

companies manufacture a single product. The difficulty of forecasting market developments, along with great R&D requirements, has led to difficult circumstances for many companies in the United States. Most of these companies have had little experience in cooperating with their customers, and they receive virtually no government financial assistance.

The semiconductor manufacturing equipment industry in Japan is entirely different in structure. Approximately 500 companies are involved in the industry, but the largest 12 account for 75 percent of sales. Manufacturing equipment producers are more closely allied with semiconductor producers, either informally or through *keiretsu* structures. Government financial support has been significant, as will be discussed later.

Semiconductor Distribution Industry

In the United States the electronic component distribution industry plays an important role in the semiconductor industry. Producers of semiconductors sell directly 75 percent of their sales through their own sales forces. Sales to distributors account for the remaining 25 percent, and distributors resell the products. Distributors service a customer base of over 150,000 firms which are generally small and medium−sized companies in the computer, telecommunications, aerospace, instrumentation, and defense industries.

Distributors provide value to the producer by servicing accounts which would otherwise not be reached. They provide value to purchasers of semiconductors by carrying inventory for short−term delivery, providing more lenient credit terms than are available from producers, and by providing value−added services such as the programmable read−only memory (PROM) and programmable array logic (PAL) devices. Semiconductors represent only 35 percent to 40 percent of the sales of the electronics components distribution industry. The remainder of their sales comes from connectors, passive components, and systems.

There is a strong movement toward greater concentration in the distribution industry. The top 25 firms now account for approximately 30 percent of sales, compared with 50 percent 10 years ago. The top six distributors account for half of the sales of the industry. There is also a trend toward territorial expansion. Regional firms have tried to expand their operations across the country, or have been acquired by larger firms. Distributors have also begun to expand their product lines, moving into computer systems and subsystems, and have even moved into semi−customization of products through the installation of design centers. This allows distributors to participate in the rapidly growing applications−specific integrated circuit (ASIC) market.

It is forecasted that the distribution industry will grow roughly at the same pace as the semiconductor producer industry, and will continue to sell about one quarter of all semiconductors sold in the United States.

The Semiconductor Industry in the United States and Japan

Although U.S. companies pioneered the development of semiconductors in the 1950s, Japanese companies fought fiercely to become the world's leading semiconductor producers, and in the 1980s achieved preeminence in many subsectors. Because of the importance of the product and the roles of both the U.S. and Japanese governments in its development, semiconductor trade has become a source of major friction between the United States and Japan. Tension occurred as U.S. companies lost market share to Japanese companies during the 1978−86 period (Figure 3.4).

While the decline in U.S. worldwide market share has been alleviated in the past few years, intense competition between U.S. companies and Japanese companies has continued.

Characteristics of the Semiconductor Industry in Japan and the United States

In 1990, semiconductor consumption in Japan was $22.5 billion, making it the largest market in the world. Consumer electronics accounted for approximately 40 percent of the demand for integrated circuits, a percentage which has been slowly declining over the years. The remaining 60 percent of IC demand was for industrial electrical equipment. Within this subsector, office computers were the largest group, with one−third of subsector demand, followed by personal computers and communications equipment. Given growing computer and telecommunications demand in Japan, it is projected that demand for semiconductors in industrial products will increase faster than demand for semiconductors in consumer products. The five largest semiconductor producers in Japan are NEC, Toshiba, Hitachi, Fujitsu, and Mitsubishi Electric. Appendix 3.1 offers a description of the size and operations of each company.

In 1990, semiconductor consumption in the United States was $17.4 billion, making this the second largest market in the world. In terms of end use markets, consumer products in the United

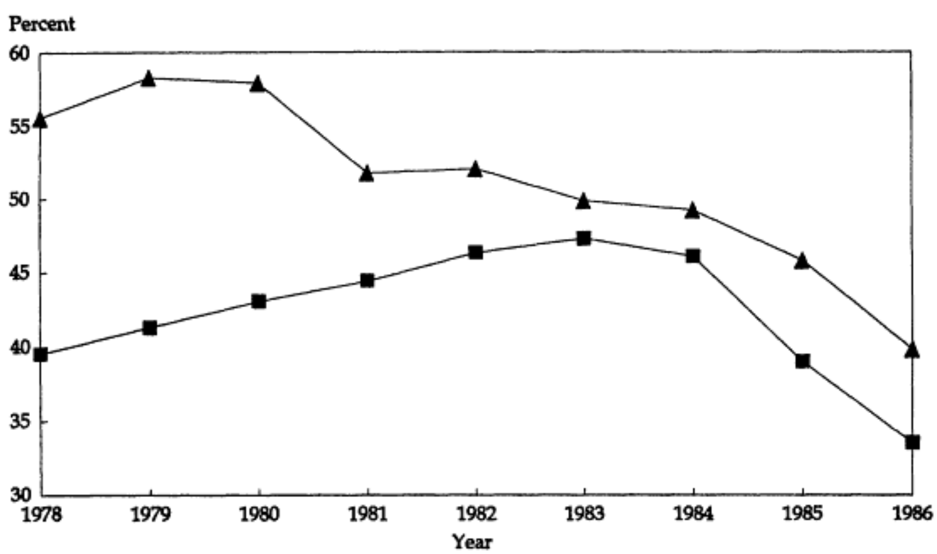

Figure 3.4
U.S. Consumption and Production of Semiconductors, 1978−86 (percentage of worldwide market)
Source: Dataquest, April 1987.

States accounted for 7 percent of demand, and military markets accounted for 14 percent of demand. The computer market accounted for 27 percent of demand, and telecommunications for 21 percent, with industrial and automotive applications accounting for the remainder. The five largest semiconductor producers in the United States are Motorola, Intel, Texas Instruments, National Semiconductor, and Advanced Micro Devices.

A number of interesting comparisons can be made about the semiconductor industries in Japan and the United States. First, most Japanese semiconductor producer operations are part of much larger, more diversified electronics companies. These companies can fund research and development, capital spending, and, if necessary, absorb operating losses better than many of the smaller semiconductor producing companies in the United States. Japanese companies have been able to outspend U.S. companies on capital investment, in both percentage of sales and in absolute terms, every year since 1981 (Table 3.1).

Japanese semiconductor operations also have built−in customers—the larger companies they are part of, to which they sell integrated circuits for use in computers, communications equipment, and consumer electronics. Again, this is in contrast to the U.S. market, which is structured differently.

Reacting to differences in market structure and corresponding effects on market share, U.S. semiconductor producers have begun to make changes in their operations to make them more competitive. In recent years, many U.S. companies have made major efforts to reduce costs. One consequence of this has been a reduction in employment levels. Another has been a tendency toward joint ventures, mergers, and acquisitions both to reduce costs and gain access to technology. In addition, U.S. companies have focused on ways of improving manufacturing efficiency and quality to compete with the Japanese. Finally, in response to the tight relationships Japanese semiconductor−producing companies have with both suppliers and customers, U.S. semiconductor−producing companies have tried to form much closer relationships with both semiconductor equipment suppliers (for example, through the SEMATECH consortium) as well as their end use customers of semiconductors. It is too soon to tell if U.S. efforts to regain their competitive edge against Japanese companies will pay off.

In both countries there are the beginnings of a shift from the use of DRAMs (where the Japanese have 90 percent of the market) to CMOS logic and microprocessors. There has also been a movement away from the production of standardized products toward more design−intensive products. Finally, U.S. and Japanese companies have begun to work together on joint ventures, with manufacturing in many cases being done in the United States.

Table 3.1
Capital Spending as a Percentage of Sales of Semiconductors in the United States and Japan, 1981−88

Year	*Japan*	*United States*
1981	16	16
1982	17	14
1983	22	16
1984	32	23
1985	32	19
1986	12	11
1987	13	13
1988	18	15

Source: Dataquest, October 1989.

The Role of the Government

Because of the importance of the semiconductor industry to the computer, telecommunications, consumer electronics, automotive, and defense industries, governments in many countries have taken an active role in promoting the development of the sector. Industrial development programs, trade policy, and financial assistance are common means of supporting the sector.

In Japan, where the initial development of the semiconductor industry lagged behind that of the United States, the Japanese government played an active role early on to assist their industry. In 1968, the production of integrated circuits in Japan was only $24 million, compared with approximately $400 million in the United States. Yet, by 1978 total IC production in Japan was $1.2 billion, compared with approximately $2.3 billion in the United States and Japanese firms had reached virtual parity with U.S. companies in certain fields such as large−scale integration metal oxide semiconductor (LSI MOS) memory. Japanese technological advances and gains in market share were helped significantly by the policies of the Japanese government to spur the development of the semiconductor industry.

The first significant step the Japanese government took was the enactment of the 1971 Law for Provisional Measures to Promote Specific Electronic and Machinery Industries. Computers and integrated circuits, magnetic disks and facsimile equipment, and advanced production techniques received special emphasis under this law. Development projects in these areas received direct funding from the Ministry of International Trade Industry (MITI) and low interest loans from the Japan Development Bank as well as favorable treatment in procurement, industrial standards, and technology upgrading. By 1977 over 60 different projects had received financial support in areas ranging from exposure to electron beams and large−scale integration (LSI) production equipment to high−performance discrete devices and basic materials research.

The best known project in terms of direct government financial support is the Very Large Scale Integrated Circuits (VLSI) Project which was formed in 1975 and began operating in 1976. Mitsubishi, Toshiba, NEC, Fujitsu, and Hitachi are members of the association. Research goals included the development of microfabrication methods, low−defect large−diameter silicon wafers, computer−aided design technology, VLSI process techniques and equipment, VLSI test equipment and techniques, VLSI logic, and memory devices. The program is generally credited with making the Japanese semiconductor industry internationally competitive by the late 1970s.

Patterns of U.S. government support for the semiconductor industry are quite different. First, U.S. government support began when semiconductors were perceived by the government as contributing to the country's defense. In the late 1950s and early 1960s, the industry received product development support from the Department of Defense and the National Aeronautics and Space Administration (NASA). At this time, the government bought virtually all of the integrated circuits that U.S. companies produced, which amounted to $4 million in 1962. The government purchased 55 percent of the integrated circuits produced in 1965; total sales were $19 million. However, by 1978, as technology advanced and applications expanded, government purchased only 10 percent of total sales, which were then approximately $3.5 billion.

Nevertheless, although military applications were a smaller percentage of the total market, semiconductors were still perceived as critical to defense. Thus, in 1978 the Department of Defense initiated the Very High Speed Integrated Circuit (VHSIC) Program, which got under way in 1980. Program goals included the development of VLSI circuits for military applications. Funding for the eight−year program was $680 million.

Although the U.S. government actively intervened to promote the development of military applications in the 1950s, 1960s, and 1970s, in stark contrast to the Japanese government's strategy it had no explicit programs to help the industry promote the development of consumer and industrial applications. By the 1980s, the U.S. semiconductor industry began to lose market share to the Japanese semiconductor industry. In some markets, such as in DRAMs, the Japanese gained an imposing 90 percent market share. Severe downward pricing pressures on U.S. companies and large financial losses for virtually every U.S. company resulting from drastic swings in demand pushed the U.S. government to act to help the civilian side of the industry.

Trade policy actions came first. In 1985 the U.S. government filed three "unfair trade" suits against Japanese companies for the dumping of DRAMs and erasable programmable read−only memory (EPROM) devices, and for denying U.S. companies access to the Japanese market. The suits were subsequently dropped in July 1986 when the U.S. and Japanese governments reached a five−year agreement on the sale of Japanese semiconductors to the United States and third countries at "fair market value." In addition, the Japanese agreed to promote the access of U.S. products to their market.

In October of 1986, however, the U.S. Semiconductor Industry Association (SIA), a trade association composed of U.S. semiconductor producing companies, claimed that the Japanese were in violation of the July agreement. In March 1987 the U.S. government found for the SIA and imposed $300 million in tariffs on Japanese goods. Sanctions were subsequently reduced and then removed in 1991.

The clamor for an industrial policy for semiconductors also grew during the mid−1980s as U.S. companies' market share declined. For instance, the 1987 Defense Science Board Report on Defense Semiconductor Dependence argued strongly for financial assistance to the industry and recommended the establishment of a Semiconductor Manufacturing Technology Institute (SEMATECH) that would develop the technology base for the efficient manufacture of advanced semiconductor devices. Other recommendations included university research programs, increased spending for R&D in semiconductor materials, devices, and manufacturing infrastructure.

The Defense Science Board's recommendations led to the formation of SEMATECH in 1987 by 14 U.S. companies, with assistance from the U.S. government. SEMATECH's stated mission was to provide United States the capability for leadership in semiconductor manufacturing, with the objective of achieving parity and then outstripping Japan in semiconductor manufacturing by 1993. It was agreed that SEMATECH would receive $100 million annually from private industry members and $100 million annually from the U.S. government from 1988 to 1993. The government commitments come from the Defense Advanced Research Projects (DARPA) of the U.S. Department of Defense (DOD).

What has SEMATECH accomplished? Although close to completing a state−of−the−art fabrication line, SEMATECH dropped its attempts to develop complete advanced manufacturing modules and processes with demonstrable product output for the industry. Rather, it has used its fabrication capabilities and much of its funds with selected U.S. integrated circuit production equipment manufacturers to ensure that one qualified U.S. supplier exists for each equipment module and manufacturing system. Progress is being made in advancing standards and best practices for various tools and processes. Major U.S. member chip manufacturers have claimed significant improved efficiencies, but nonmember companies alleged that in the past equipment hold−back policies and non−open publication of findings have denied them any benefits from the consortium's work.

SEMATECH has strengthened a number of firms in the multibillion−dollar IC equipment market, but smaller firms that are not involved in the cooperative programs have been left behind. Such a rationalizing, industrial policy role for a quasi−public agency in a domestic subsector infrastructure has been a source of controversy.

SEMATECH is currently engaged in a drive for another five−year, $200−million−per−year extension, to be shared equally by the U.S. government and by industry members. Its new objectives are to stress software modeling and simulation approaches to computer integrated manufacturing on specific generic IC manufacturing processes. Full system integration will be left to the member companies. A fabrication line for 1996 is promised to put the U.S. ahead of Japan, without any product exemplars. The close working relationship with the selected equipment vendors is planned to continue, with the fabrication line used for evaluation and debugging.

Several industry members have dropped out of SEMATECH, and some smaller companies are reevaluating their membership. Major semiconductor producer members, however, appear intent on remaining. The government is examining its level of support for the next period, with $80 to $100 million per year support under discussion. DARPA has indicated it would recommend participation on some level, but now demands a project by project review throughout the next period which would be a significant change.

SEMATECH has provided significant benefits for a number of its member companies and the supported IC equipment manufacturers. At what

level it has aided the industry as a whole in relationship to the $1 billion investment is a topic of current debate.

The Semiconductor Industry in the Republic of Korea, Taiwan (China), and Europe

The Republic of Korea

The semiconductor industry in Korea is smaller than those in the United States and Japan, but has the potential for rapid growth, as does the entire electronics industry in Korea. From 1970 to 1985 the Korean electronics industry grew at an annual rate of 34 percent. However, the industry has suffered from the worldwide slowdown in the semiconductor industry, as well as factors within Korea such as inflation and unfavorable currency rates. Nevertheless, several of the Korean electronics companies made major strides in the semiconductor industry. For example, Samsung was ranked fifteenth in world market share in 1990. The Korean electronics industry has received government support in the form of low interest rate loans, tax incentives, partially funded R&D programs, and protective tariffs.

The Korean semiconductor industry began in the 1960s when U.S. companies located assembly operations in Korea mainly to source inexpensive Korean labor. During the 1970s a few local firms began producing wafers for mature products. During the mid−1980s, several Korean firms made major purchases of advanced wafer fabrication equipment and began to increase local production of wafers. Only 5 of the more than 30 Korean semiconductor companies have wafer fabrication lines, and these 5 account for more than 91 percent of Korean IC sales. There are four major Korean semiconductor producers: Samsung, Hyundai, Daewoo, and Lucky Goldstar. The semiconductor operations in each of these companies is a relatively small part of a large, diversified company.

The Korean semiconductor industry faces three principal challenges. First, the industry is currently dependent on U.S. and Japanese product and process technology. Indigenous technological capabilities remain to be developed. Second, the industry is dependent on export markets. In climates of heightened protectionism and recession, the industry is vulnerable. Third, Korea now must face new competition from developing countries which have even lower labor costs. In order to remain attractive as a manufacturing site, and for its companies to remain competitive, the industry must continue to upgrade its product mix to high value−added products.

Taiwan (China)

Though small in relation to Japan's, or even Korea's, semiconductor industry, the semiconductor industry in Taiwan (China) has made good progress in recent years. The four largest producers are United Microelectronics Corporation, Tai−wan Semiconductor Manufacturing Corporation, Hualon Microelectronics, and Winbond. Total sales of these companies were $400 million in 1990. Major products are DRAMs, static random access memory (SRAM) devices, ASICS, and telecommunications devices. Taiwan (China) faces the same challenges as Korea as it is now not a low wage location and must continue to upgrade its product mix to be globally competitive.

Europe

Total semiconductor consumption in Europe in 1990 was $10.7 billion, or 18.3 percent of world consumption. Dataquest forecasts that European consumption will be $20.8 billion in 1995, a compound annual growth rate of 14.3 percent. This is higher than the growth rate forecast for North America or Japan and reflects the somewhat later computerization of offices on the continent. Only 3 of the top 20 semiconductor producers in the world are European companies: Philips, SGS−Thomson, and Siemens. They are all divisions of much larger companies which produce other types of electronics products.

In spite of strong growth potential, the semiconductor industry in Europe faces several strong challenges. The first is the dropping of border controls within the European Community (EC) in 1992. The second is that much of the new capacity being added is owned by companies from either Japan or the United States. A third is that too much capacity may be put in place, which could seriously affect future profitability.

The EC has been aggressive in protecting its semiconductor industry. In addition to high tariff barriers against semiconductors not fabricated within the EC, the EC has also provided funding for JESSI (Joint European Submicron Silicon Initiative) which has included major involvements by Siemens and SGS−Thompson.

Conclusion

New entrants to the semiconductor industry face three challenges in the 1990s. First, the major global competitors are large companies and their size and resources are formidable. Semiconductor operations are only a part of their activities. Taking advantage of a large and more diversified revenue

base, they can make the capital and R&D investments necessary to remain competitive in the industry. In addition, they have built−in customers for semiconductors: other parts of their operations manufacture the computers or telecommunications equipment or consumer electronics products that rely on semiconductors. These large companies, then, have cost and product design advantages.

Second, major global competitors that are not part of large companies compete instead in small highly advanced niche markets. These require leading edge design and manufacturing technology.

Finally, as the perceived importance of semiconductors increases, not only to electronics industry development but also to economic growth and the technological sophistication and quality of other products, governments may take certain actions to enhance the capabilities of national companies. Thus, competition will occur not only among companies, but also among states. Industrial policy, trade disputes, and protectionism may disrupt normal market forces.

In conclusion, there will continue to be rapid change and growth in the semiconductor sector. Major producers will continue to face intense competition in world markets, and new entrants will have to overcome formidable capital, technological and policy hurdles if they are to achieve success.

Appendix 3.1 Global Leaders in Semiconductor Production

Japan

NEC is the largest semiconductor producer in Japan and the world, with 1990 semiconductor sales of $4.9 billion, and total company sales of $24.4 billion. The four major product groups of the company are communications, computers and industrial electronics, electronic devices, and home electronics. In semiconductors, NEC has memory (DRAM and SRAM), logic, microprocessor, gate array and discrete products.

Toshiba is the second largest semiconductor producer in Japan and the world, with 1990 semiconductor sales of $4.8 billion, and total company sales of $30.2 billion. The company is divided into four major product groups including industrial electronics and components, consumer products, heavy electrical apparatus, and machinery and materials. Semiconductor products include memory (DRAM and SRAM), logic, and discretes (second largest producer of discretes in the world).

Hitachi is the third largest semiconductor producer in Japan and the world, with 1990 semiconductor sales of $3.9 billion, and total company sales of $50.7 billion. The five product groups of the company are power systems and equipment, consumer products, information, communications, and devices, industrial machinery, wire, cable, metals and other. Semiconductor products include memory (DRAM and EPROM), microprocessor, specialized logic, gate arrays, and discretes.

Fujitsu is the fourth largest semiconductor producer in Japan and the sixth largest producer in the world, with 1990 semiconductor sales of $2.9 billion, and total company sales of $18.0 billion. The four product groups of the company are computers and data processing, communications systems, semiconductor and electronic devices, and car and audio electronics. Semiconductor products include memory (DRAM), gate arrays (transistor−translator log (TTL) and emitter coupled logic [ECL]), CMOS logic, and discretes.

Mitsubishi Electric is the fifth largest semiconductor producer in Japan and the eighth largest in the world, with 1990 semiconductor sales of $2.3 billion, and total company sales of $21.2 billion. The four product groups in the company are heavy machinery, information and communications systems, consumer products, and industrial products and automotive. Semiconductor products include memory (DRAM, EPROM and SRAM), linear, logic and microprocessors.

United States

Motorola is the largest U.S. semiconductor producer with 1990 semiconductor sales of $3.7 billion, and total company sales of $10.9 billion. Motorola ranks fourth in the world in total semiconductor sales. In addition to semiconductors, the company is also involved in communications, information systems, general systems, and automotive and industrial electronics. In the semiconductor sector, Motorola has large positions in logic and analog products, discretes (largest in the world), microprocessors, memory, and ASIC products.

Intel Corporation is the second largest producer in the United States with 1990 semiconductor sales of $3.2 billion, and total company sales of $3.9 billion. Intel ranks fifth in the world in total semiconductor sales. The majority of semiconductor sales were microprocessors and microcontrollers, with the remainder accounted for by memory products. The nonsemiconductor sales are systems products.

Texas Instruments is the third largest U.S. semiconductor producer with 1990 sales of $2.6 billion, and total company sales of $6.6 billion. The company ranked seventh in the world in semiconductor sales. Texas Instruments also has a large defense electronics business. In the semiconductor business the company has major positions in logic and analog products, memory (currently the only major merchant producer of DRAMs), microcontrollers and ASIC products.

National Semiconductor Corporation is the fourth largest U.S. semiconductor company, with 1990 sales of $1.7 billion, essentially all of which was in the semiconductor business. The company ranked eleventh in the world market share. National has major positions in analog and logic products, plus positions in microprocessors and microcontrollers, memory products, ASIC products, and discretes.

Advanced Micro Devices is the fifth largest U.S. semiconductor producer with 1990 sales of $1.0 billion, all of which was in semiconductors. The company ranked nineteenth in the world in market share. The company has positions in logic, analog, memory (EPROM), and PALs.

The Republic of Korea

Samsung is the largest semiconductor producer in Korea, with 1990 sales of $1.3 billion, the fifteenth largest sales base in the world in semiconductors. Total company sales were $45.0 billion. The company is the leading Korean producer of memory products (DRAMs, SRAMs, EPROMs) and logic devices and also manufacturers linear and discrete devices.

Hyundai began semiconductor production in 1986 and had $250 million in sales in 1990. The company produces memory devices (DRAMs, SRAMs, EPROMs), microcontrollers, and microprocessors.

Daewoo entered the semiconductor business early in 1987 and had 1990 sales of an estimated $100 million, much of it in the memory business (DRAMs). Total company sales were $22.3 billion.

Lucky Goldstar entered the semiconductor business in 1979 through a joint venture with AT&T, and began production in late 1980. Estimated semiconductor sales for 1990 were $140 million, with total company sales of $42 billion.

Taiwan (China)

There are five semiconductor manufacturing companies: *United Microelectronics Corporation, Taiwan Semiconductor Manufacturing Corporation, Hualon Microelectronics* , and *Winbond* . The total sales of these corporations are only a few hundred million dollars per year at the current time, and the major products are DRAMs, SRAMS, ASICS, and telecommunications devices.

Europe

Philips was the ninth largest semiconductor producer in the world in 1990, with sales of $2.0 billion, and total company sales of $30.9 billion.

SGS−Thomson was ranked twelfth in the world in semiconductor sales in 1990 with sales of $1.5 billion, and total company sales of $13.8 billion.

Siemens was ranked sixteenth in the world in semiconductor sales in 1990 with sales of $1.2 billion, and total company sales of $39.2 billion. The company is a strong producer of DRAMs, although it entered the market somewhat late.

4—
The Computer Industry

Kenneth Flamm

The invention and use of the computer represents a revolutionary technological leap forward, a technical advance of extraordinary economic and social significance. To gauge its impact, compare it to the first "industrial" revolution described by economic historians, which transformed England during the warring decades of the eighteenth century and well into the next. The single commodity which fell most in price was cotton cloth, which plummeted at an annual rate of 3.1 percent.[1] One may protest that the first industrial revolution was at its heart a cheapening in the cost of mechanical energy which far exceeded its measurable impact on the cost of products in which it was an input. Economic historians report that the marginal cost of mechanical energy dropped by 50 percent over the 50 years of most rapid change.[2]

Recently, a number of studies have attempted to measure technical progress in computers, and the contrast is striking. In all of these studies, average rates of decline in real, quality−adjusted computer prices have exceeded 20 percent per year, and perhaps even 25 percent per year.[3] Technological advance seems to have resulted in a continuous decline in cost for an economically significant good almost a full order of magnitude greater than anything seen during the first great industrial revolution, and probably the longest sustained (over four decades now) steep decline in price seen in recorded economic history.

This extraordinary rate of technological progress has brought with it enormous economic consequences. Some simple approximations suggest that just one year's technological progress brings with it to industrial users of computers in the United States a social benefit equivalent to 0.3 to 0.8 percent of gross national product (GNP), a significant chunk indeed in an era of 2 to 3 percent annual growth rates.[4]

Capturing some of the economic gains from continued technological advance in computers must certainly be one of the major reasons why developing countries are today interested in learning to use and produce computer technology. But it is not the only reason. The first, staggeringly large investments in computer technology were made for military reasons, and national security objectives continue to be a major force driving developments at the leading edge of the "envelope" of computer technology, particularly in the United States.[5] Although these forces may also play some role in pushing the newly industrialized economies (NIEs) into computers, the main motivation seems to be economic. It is the economic aspects of the computer industry, and their implications for NIEs, that will be considered in this chapter.

First, the most significant features of the industry, as it has developed in developed countries, are briefly reviewed. Then some recent changes that are transforming the nature of competition in this sector are discussed. Last, some implications for computer−related policies in NIEs are presented.

Key Features of the Computer Industry

Historically, computers have been characterized by a high rate of technological progress, heavy research and development (R&D) intensity, and extensive involvement of government in technology development. Each of these has consequences for the structure of the industry.

High Rate of Technological Progress

The aggregate economic significance of this technological advance has already been mentioned. But the very nature of growth and competition in this industry is also tightly linked to the extraordinarily rapid pace of innovation.

That the share of computer shipments in GNP has been steadily rising—until it today approaches 2 percent in the United States—in the face of plummeting prices means that demand must be highly price−elastic. Indeed, the few available quantitative estimates suggest a price elasticity of demand in the −1.4 to −1.5 range, meaning that a 10 percent decline in price results in a 15 percent increase in demand for computing power if all else is equal.

For the industry, this has meant that computer demand has always been expanding by leaps and bounds, with computers penetrating into new industries and applications as the price of computing power has dropped. New niches for specialized systems, new uses for cheap computing power have constantly been opening up. Such niches have grown rapidly into huge established markets with further price declines. Targeting new niches and applications has always been, and continues to be, one of the most successful strategies for entering the computer hardware business. Most of the success stories of entry into the U.S. industry involve some variant of this tactic: Digital Equipment pioneering the minicomputer in academic and scientific markets, Control Data and later Cray focusing on supercomputers, Apple pioneering the microcomputer. While European companies have not on the whole been particularly successful, similar pursuits of brand new markets characterize the most successful of the European firms: Nixdorf, for example, with the minicomputer, and Norsk Data introducing the high−performance super−mini into European markets.

In established, mature markets, by way of contrast, large firms have tended to dominate established applications, in part because of significant economies of scale and scope. Small firms pioneering new markets have either grown large and come to dominate the maturing markets they pioneered, or have gone broke, or have been absorbed into large firms servicing those established markets. One of the main sources of those economies of scale has been the heavy technology−intensity of computer production.

Heavy R&D Intensity

If technology intensity is measured by either research and development expense as a share of sales, or R&D scientists and engineers per thousand employees, computers rank at the very top of commercially−oriented industries (Table 4.1), spending over 13 percent of sales and employing 132 researchers per 1,000 employees. If federally−funded R&D is added, aircraft and missiles spend a higher share of their revenues on R&D, but this is essentially a military and defense−oriented sector. Among commercial industries, the runner−up, drugs and medicines, spending 9.3 percent of sales on R&D, trails substantially behind computers.

The highly research−intensive nature of computer production has had many significant consequences for the computer industry. Perhaps the most noticeable has been important economies of scale and scope in the production of equipment drawing on the results of those R&D investments. To a first approximation, whether one produces 10 computers or 10,000 computers, the costs of developing the machine are roughly constant. Thus, the larger the sales base, the lower the average unit cost of producing computer hardware.

These economies of scale in the use of the outcomes of R&D have created an unrelenting pressure for manufacturers to seek out the widest possible market for their products, to maximize the return on their relatively fixed R&D investments. As a consequence, the industry has been international in focus right from the start. Major producers quickly turned to foreign markets in their quest for a larger sales base.

The relative fixity and great importance of R&D costs have also pushed computer companies to utilize that R&D in a range of different products, addressing the needs of different markets, in order to reap economies of scope. Since the mid−1960s, the concept of compatibility—the creation of standards which allow hardware and software to be used on a variety of different computer models—has been a major tool used by both computer producers and consumers to reduce their costs of producing and using computers. The evolution of standards and compatibility issues within the international computer industry has become the focus for a major change in patterns of competition within the industry, and this transition is discussed in greater detail below.

The interplay between industry structure and firm strategies in a technology−intensive industry have created a pattern of competition which is particularly striking in the computer industry. Historically, small firms have been disproportionately important in introducing new technologies or addressing new market niches, while larger firms have been most successful in relatively mature markets. I have argued[6] elsewhere that this complex ecology is due to what has been dubbed the "Arrow effect," not because of the arrows sticking out of the backs of pioneers, but because the argument was first made by economist Kenneth Arrow.[7] Briefly, when a firm has an unthreatened monopoly in a particular market or application, the profits from introducing a new product or process

Table 4.1
Technology Intensity of U.S. Manufacturing Industries, 1989

Industry	*SIC code*	*Company and other (excluding federal) R&D funds as a percentage of net sales*	*Number of R&D scientists and engineers per 1,000 employees*
Food, kindred, and tobacco products	20, 21	0.5	7
Textiles and apparel	22, 23	0.4	
Lumber, wood products, and furniture	24, 25	0.7	5
Paper and allied products	26	0.7	11
Chemicals and allied products	28	5.3	72
Industrial chemicals	281−82, 286	4.3	55
Drugs and medicines	283	9.3	101
Other chemicals	284−85, 287−89	3.5	65
Petroleum refining and extraction	13, 29	1.0	26
Rubber products	30	1.7	18
Stone, clay, and glass products	32	2.3	28
Primary metals	33	0.9	13
Ferrous metals and products	331−32, 3398−99	0.6	9
Nonferrous metals and products	333−36	1.2	17
Fabricated metal products	34	1.1	
Machinery	35	7.8	76
Office, computing, and accounting machines	357	13.4	132
Other machinery, except electrical	351−56, 358−59	3.0	30
Electrical equipment	36	5.3	72
Radio and TV receiving equipment	365	2.9	51
Communication equipment	366	5.4	83
Electronic components	367	8.3	108
Other electrical equipment	361−64, 369	2.3	30
Transportation equipment	37	3.7	74
Motor vehicles and motor vehicle equipment	371	3.8	41
Other transportation equipment	373−75, 379	2.3	50

Aircraft and missiles	372, 376	3.6	103
Professional and scientific instruments	38	7.2	72
Scientific and mechanical measuring instruments	381−82	8.5	106
Optical surgical photographic, and other instruments	383−87	6.7	56
Other manufacturing industries	27, 31, 39	1.0	16
Total		3.1	49

Note: The number of R&D scientists and engineers per 1,000 employees for 1989 was derived by dividing the arithmetic mean of scientists and engineers employed in January 1989 and January 1990 by the number of employees in all activities in March 1989.

Source: National Science Foundation.

are to some extent offset by reduced profits on obsolete products or processes which are displaced. A firm with no existing product line, on the other hand, which can become a monopolist on the strength of a significant new technology, has no existing product line to write off, and thus earns a greater private return on the same technology investment.

The historical introduction of the microcomputer is a probably a tolerably good approximation to the Arrow effect in action. When start−up Apple brought out the Apple II in 1977, it had no existing product lines threatened by rising sales of its new computers. IBM did not react and introduce the IBM personal computer (PC) until late 1981, and the impact on its sales tells much of the story on the reasons for its slow response. In a period of vigorously growing demand for computers, its PC sales shot up like a rocket: its microcomputer revenues grew by $2.1 billion between 1982 and 1983. However, this was offset by absolute *declines* of $400 million in office systems and

$200 million in minicomputers over the same period. Apple had no such offsetting losses when it brought out its new product.

Thus, older incumbent firms dominating mature markets have good economic reasons for moving more conservatively in bringing out new technology, while young start−ups can achieve greater returns from the same innovations. Historically, many new computer start−ups have originated with engineers and technical people from established firms, disgruntled with the slow pace at which the new technology they worked on was introduced, leaving the established company and striking out on their own to bring the technology to market. From this perspective, large, established firms and new start−ups play different social roles in a complex industrial ecology. The large incumbent firms reap economies of scale and scope in established markets. The small start−ups pioneer new markets and technologies, and grow into large firms as the markets mature, or they die or get absorbed into large firms.

If one accepts this view, recent discussions suggesting that either established, large, integrated firms, or small, entrepreneurial start−ups are somehow better than the other (and therefore that the other form of industrial organization is to be avoided and to blame for competitive problems in the electronics industry) are misguided.[8] Big and small firms are neither "good" nor "bad" per se, but serve different functions within the industry, coexisting in a symbiotic relationship.

Finally, the heavy research intensity of the computer industry goes hand−in−hand with continued extensive involvement by governments in the industry. For a variety of reasons—particularly the inability of private firms to appropriate the results of the most fundamental and radical sorts of R&D projects for their exclusive use—economists argue that social returns to R&D generally exceed private gains. This has created a logic that pushes government involvement in the industry, particularly in investments in the technology base.

Government's Role in Computers

Government involvement in computer technology was originally motivated by national security objectives. But in the late 1950s, and early 1960s, as the growing economic consequences of the technology became apparent, government initiatives in computers motivated by a desire to capture economic returns—particularly in Europe and Japan—took shape. These efforts encompassed the creation of trade barriers around the domestic market, in order to provide a sheltered national market, and subsidies to technology investments. In Europe, the sheltered national market was handed over to "national champion" firms, essentially conceived as national scale models of IBM. These protected national champions never really emerged from their sheltered niche into the international marketplace, and these policies (followed to a greater or lesser extent in Britain, France, and Germany) are now widely acknowledged to have been failures.

In Japan, on the other hand, competition among firms was encouraged within the national market, and emphasis was given to exports and the production of internationally competitive products. In the 1970s, formal barriers to computer imports were removed. Technology subsidies were organized through cooperative joint research projects. Today, Japanese firms are serious challengers to the traditional hegemony of U.S. computer companies in the world market, and those policies must be viewed as a successful response to the conditions of the time. However, the computer industry is moving through a period of transition, and it is not clear whether the formulas of the 1960s and 1970s are appropriate for the 1990s.

In the United States, military programs continue to be the primary vehicle for government investments in computer technology. It is not clear if this will continue to be a particularly effective way to invest in the commercial technology base in the world of technological peers and competitors that the United States entered in the 1980s. A debate over how to restructure those investments in order to increase commercial relevance has moved to center stage in the United States.9

The bottom line is that government plays a central role in investments in computer technology around the world. In the United States, in the early 1980s, government paid for perhaps 66 to 75 percent of basic research in the area, 40 percent of all research, and perhaps 20 percent of research and development.10 These numbers reinforce the point that government is most important in funding the least appropriable, most basic sorts of investments, while private industry dominates the development of commercial products building on that technology base (80 to 85 percent of R&D performed by U.S. companies is development, not research; only 1.5 to 2 percent of industrial computer R&D is basic research).

The practical significance of the ubiquitous role of government in technology investments is that such involvement is one of the rules of the game everywhere. This involvement is so pervasive that it is not controversial. Opinions diverge and political pressures play a role in circumscribing policy options in the erection of barriers to trade and investment around national markets. This issue is particularly tricky in the computer industry, since every firm that is a significant player in the industry has a major presence in international markets. Because becoming a competitive force in the industry is difficult without access to the international marketplace (and the technologies and competitive pressures that foreign producers bring with them when they enter the national market), and because gaining access to foreign markets without in turn opening one's domestic market is increasingly difficult, strong pressures to permit some sort of access by foreign computer companies to the national market inevitably work against even the most determinedly protectionist policies.

Recent Trends

While the phenomena described above have been felt throughout the history of the computer industry, the unceasing change, ferment, and turmoil produced by these elements has been an equally constant feature of the industry. In the early 1990s, one can trace out some of the most important changes shaping what will clearly be a new and different industry structure.

Continued Internationalization

The main consequence of the relative fixity of R&D costs for the structure of the industry has been a constant expansion into the international marketplace. Table 4.2 shows the trend for U.S. computer companies. In recent years, foreign sales have typically accounted for 40 to 50 percent of the revenues of U.S. computer companies.

To be successful in the computer business, corn−parties have had to reach out to the global market. With no exceptions, world−class firms have eventually had to produce products competitive in the international marketplace. An inward−looking strategy—taking shelter behind trade barriers in a protected national market—has never proved successful in the long run.

Because governments' historical interest in computers has been longstanding and intense, and national policies have frequently encouraged the domestic production and manufacture of computers, the quest for international markets has frequently led to direct investment in a foreign subsidiary, rather than to export sales. This is clearly reflected in available statistics on the revenues of U.S. computer multinationals (Table 4.3). In 1982, exports by U.S. computer firms to unaffiliated foreign customers were less than $1.2 billion, compared with $43.6 billion in domestic sales. Despite the high value of the dollar that year, foreign subsidiary sales weighed in at $27.2 billion, or 40 percent of worldwide sales. That share had risen to over 60 percent by 1989.

The portrait painted by Table 4.3 also shows that royalties and fees on sales of technology to unaffiliated domestic and foreign customers brought in less than 0.03 percent of revenues from product sales. Clearly, formal sales of computer technology through licensing agreements are an insignificant avenue of technology transfer. Computer companies (excluding perhaps those facing impending financial disaster) are exceedingly

Table 4.2
Importance of Foreign Markets to the American Computer Industry, Selected Years
(foreign revenues as a percentage of total revenues)

Firm	*1960*	*1964*	*1969*	*1974*	*1979*	*1983*	*1985*
Burroughs			30	37	44	41	44
Control Data			26	31	32	24	29
Data General					27	31	32
Digital			24	39	36	35	39
Hewlett−Packard					49	37	37
Honeywell		18	33	41	27	26	25
IBM	20	29	35	47	54	42	43
NCR	41		41	51	54	46	46
Sperry	20	28	31	43	40	30	30

Wang					33	28	31
Unweighted average	27	25	31	41	40	34	36

Source: Flamm, Kenneth, *Creating the Computer: Government, Industry, and High Technology* (Washington: Brookings Institution), 1988, p. 101.

Table 4.3 Worldwide Operations of U.S. Computer Firms, Selected Years

Category	*1977*	*1982*	*1989*
Parent firms (US$ billions)			
1. Domestic sales	20.5	43.6	61.9a
2. Net royalties and fees received from unaffiliated sources	0.02	0.02	−
3. Export sales to unaffiliated customers	0.6	1.2	7.0
4. R&D performed for self	2.2	4.6	10.6
5. R&D performed for U.S. government	−	0.9	1.2b
Majority−owned affiliates (US$ billions)			
6. Sales to unaffiliated customers	16.4	27.2	103.1c
7. Net royalties and fees received from unaffiliated sources	−	0	−
8. R&D performed by affiliates	−	0.6	1.4d
Structure of operations			
Foreign sales as a percentage of worldwide sales [3+6)/(1+3+6)]	45.4	39.5	64.0
Foreign R&D as a percentage of worldwide R&D [8/(4+5+8)]	−	9.8	10.3
Parent R&D for self as a percentage of parent sales [4/(1+3)]	9.2	9.0	15.4
All parent R&D as a percentage of parent sales [(4+5)/(1+3)]	−	10.8	17.1
Worldwide R&D as a percentage of worldwide sales [(4+5+8)/(1+3+6)]	−	8.5	7.6

− Not available.

a . Total parent sales—exports shipped by parent to affiliates—exports shipped by parent to other foreign companies.

b . Performed for U.S. government and others in 1989.

c . Majority−owned affiliate sales less majority−owned affiliate exports to parent in 1989.

d . Industry of affiliate (not industry of parent) is computing and office equipment in 1989.

Source: For 1977 and 1982: Flamm, *Targeting the Computer: Government, Industry, and High Technology* (Washington: Brookings Institution), 1987, table 1−4; For 1989: U.S. Department of Commerce, Bureau of Economic Analysis, *U.S. Direct Investment Abroad* , Washington, D.C., 1991.

reluctant to sell rights to their mainstream technologies at arm's length, and on those rare occasions when they do, they typically sell rights to older vintage technology that has been rendered obsolete by more recent innovations.

Instead, people seem to be the most important medium of technology transfer. The movement of trained people from research labs to industry, and from company to company, tracks the birth of new computer companies, new markets, and new technologies. In computers, as in semiconductors, an inverted tree is a reasonable approximation of relationships between companies and technologies over time.

The internationalization of the industry has moved hand−in−hand with the internationalization of the technology. Within a multinational computer firm, people and know−how flow across national boundaries in the pursuit of its economic serf−interest. The local subsidiaries of multinational computer companies, particularly in large, developed countries, have to some extent transferred computer technology through the training of local employees, who take their knowledge with them when they move on to another employer. Conversely, the firm will seek out new technology and ideas wherever they are found, and attempt to tap into them. At the international level firms have realized that local R&D laboratories and subsidiaries can tap into national research communities around the globe. Figure 4.3 shows that R&D performed by foreign affiliates of U.S. computer multinationals accounted for about 10 percent of worldwide R&D in 1982.

The Drive Toward Standards

The relative fixity of R&D cost has also meant that producing a wide range of products drawing on the underlying R&D base has increased the re−

turns to those R&D investments. One way to increase such economies of scope in the utilization of R&D has been to define standards for computer hardware and software that allow products developed for one system design to perform with others as well. Apart from the economies standardization creates in the production of new products, and consequent declines in cost, standards bring additional benefits to users of computer products. Since users typically make large investments in learning how to use computer systems, standards may mean substantial cost savings when they run many distinct applications on the computers they use. Since computer users typically want to share information with other computer users, use of standards allows them to communicate more cheaply and to enjoy so−called network externalities.

The benefits of standardization are traded off against the performance gains that specialization can bring in a single application. That is one reason why pioneering a new market or application has often been a successful strategy for a newcomer to enter the computer hardware business, despite the economies of scale and scope that an established firm, with a large installed base, enjoys in a relatively mature application. An application requires both hardware and software. In an existing, mature application, a new and incompatible machine with superior price−performance will require new software as well while an older machine which makes use of existing software requires no new software investment. The total systems cost with the new hardware, therefore, will typically exceed that with the older, inferior hardware, despite a substantial gain in hardware price−performance. In a new application, however, new software investment is inevitable no matter which hardware is used, and a substantial price−performance advantage for the new hardware can much more readily be translated into a decrease in total system cost.

The benefits of standards were learned by trial and error during the historical evolution of the industry, and changes in the standardization strategies of firms have often marked periods of transition and consolidation in the industry. The early days of the industry, in the 1950s, were dominated by the attempts of firms to take the infant technology and apply it to particular market and applications niches. The first mammoth computers (built with government funds) were adapted to scientific and business needs, with large and small models targeting particular kinds of applications. As the technology was differentiated, models proliferated. By the early 1960s, a virtual Babel of computers existed, with different models manufactured by a single producer often requiring totally different kinds of peripherals and software.

In the mid−1960s, IBM introduced its System 360 computer line, which transformed the industry. For the first time, a whole range of hardware models used a common set of peripherals and software. Users quickly learned to appreciate the cost benefits of standardization, and IBM's initial lead in the computer marketplace was cemented firmly into place. Other producers of mainframes eventually reacted by consolidating their many models into a single architectural family, but by the time this had happened, IBM had a huge lead in installed base. The late 1960s and early 1970s saw many of IBM's strongest and most substantial rivals exit from the mainframe computer business.

One of those competitors, RCA, appreciated the significance of IBM's innovation, and introduced a family of computers designed to tap into IBM's installed base: a series of computers with some degree of compatibility with the IBM standard. RCA's adherence to the standard, however, was incomplete: IBM software generally had to be modified to run on the RCA machines, and IBM peripherals could not be attached. RCA's effort flopped, and it quit the computer business.

The idea of producing IBM−compatible hardware, however, lived on, and in the late 1960s and early 1970s, several companies began to produce computers and peripherals that were "plug−compatible" with IBM equipment. The most successful were two Japanese companies—Hitachi, whose computer designs had initially been licensed from RCA while RCA was still on the scene, and Fujitsu, which became the largest single shareholder in Amdahl a new venture in IBM plug−compatible computers started up by Gene Amdahl, formerly one of IBM's top system designers. Hitachi and Fujitsu were to prove relatively successful with this strategy, mainly on the basis of large investments in state−of−the−art semiconductor technology used to maintain a price−performance edge over IBM equipment using less advanced semiconductors. This strategy was difficult to follow, however, since IBM was free to change its standards at will and confound its would−be imitators. IBM could and did do precisely that.

IBM's freedom to change its proprietary standard at will, coupled with aggressive legal maneuvers by IBM to assert control over its architecture, made it more and more difficult for the Japanese plug−compatible manufacturers to make a profit in the IBM mainframe market. In the 1980s these firms, and others, increasingly favored a new strategy that began to take shape: marketing products that conformed to nonproprietary industry standards.

The germ of this new strategy was formed in the early 1970s, when researchers at AT&T's Bell Telephone Laboratories designed a new operating system, UNIX, with the aim of porting it easily from one type of hardware to another. UNIX was distributed freely to researchers at universities in the United States, who modified and improved the original AT&T code. Soon, variants of UNIX were running on high−performance minicomputers that were appearing in large numbers at universities. Eventually, the University of California at Berkeley started a project, funded by the military, to incorporate advanced network features into UNIX, so that computers running the system could easily communicate with the ARPANET, the military's pioneering packet−switched, wide area computer network.

Other fledgling computer companies soon realized that by supporting UNIX on their new products, they could tap into a large and growing university and defense computer base, a market that in any event would be among the most likely targets for new, advanced, high−performance hardware. The Europeans, faced with the collapse of their "national champion" strategies, became interested in UNIX as a vehicle for combining their relatively small user bases into an aggregate that could at least begin to approach the economic advantages of the enormous IBM user base. Standards organizations were formed to settle on a single European UNIX, and were joined by U.S. sympathizers. The Japanese—running to catch up with IBM after its latest strategic change in its standards, and under attack on intellectual property issues by an army of IBM lawyers—also began to think seriously about switching over to UNIX. The also−ran U.S. mainframe computer companies like Burroughs, Sperry (later to merge with Burroughs into Unisys), NCR, Honeywell, even super computer producer Cray, also began to introduce products supporting UNIX. The U.S. government lent its imprimatur to the trend, by specifying UNIX−like specifications for much of its computer procurement.

By the mid−1980s, UNIX was firmly established as an alternative to proprietary standards, and rapidly gaining ground. The emergence of a nonproprietary, international industry standard operating system coincided with the creation of another set of de facto nonproprietary hardware and software standards, those associated with the IBM personal computer.

The decision by IBM to put its PC standard into the public domain was a tactical move, designed to overcome its late entry into the PC market. That decision turned out to have great strategic consequences. Competitors were free to produce IBM−compatible PC hardware using industry−standard parts, with relatively low R&D costs. Exceedingly attractive price−performance made PCs turned out by a highly competitive industry instant winners with computer users. PC shipments rose sharply, and today, desktop systems account for about half of U.S. computer sales (Figure 4.1). The IBM PC standard and its associated operating systems (MS−DOS, and its successor OS/2, licensed by software producer Microsoft to all comers at reasonable rates) constitute de facto international, non−proprietary standards.

Today, more computer dollars are spent by installations using nonproprietary standards UNIX and MS−DOS−OS/2 than are expended by users using the principal proprietary standards, IBM mainframe and mini operating systems and Digital Equipment's VMS operating system (Figure 4.2). Furthermore, many manufacturers shipping computers using operating systems falling in the "other" category are committed to supporting UNIX, and much of that slice of pie will surely be joined to UNIX in coming years.

This movement toward nonproprietary international standards is reshaping the nature of industrial competition in computers. It is best understood as a floating crap game of governments and corporations formed into shifting, rival coalitions, maneuvering for what they perceive to be their self interest. Even IBM and Digital are under pressure to support the UNIX standards, and their role in a recent schism in the UNIX world—promoting the formation of another competing standards organization attempting to define the UNIX standard—is portrayed by some as a complex stratagem to make their proprietary standards look more attractive. In any event, the computer industry is making a transition to a brave new world where nonproprietary international standards will be a force shaping competition, and the structure of that new environment is not yet entirely clear.

The Rise of Intellectual Property Issues

Another recent development of great significance to developing countries has been the rise of intellectual property issues as a significant factor in competition between firms. In the early days, when the computer industry was basically a U.S. enterprise, patent and copyright issues played little role. This was due to (a) the government−funded roots of the technology, which made it difficult for private firms to assert title to concepts; (b) to disputes among researchers, which had been settled

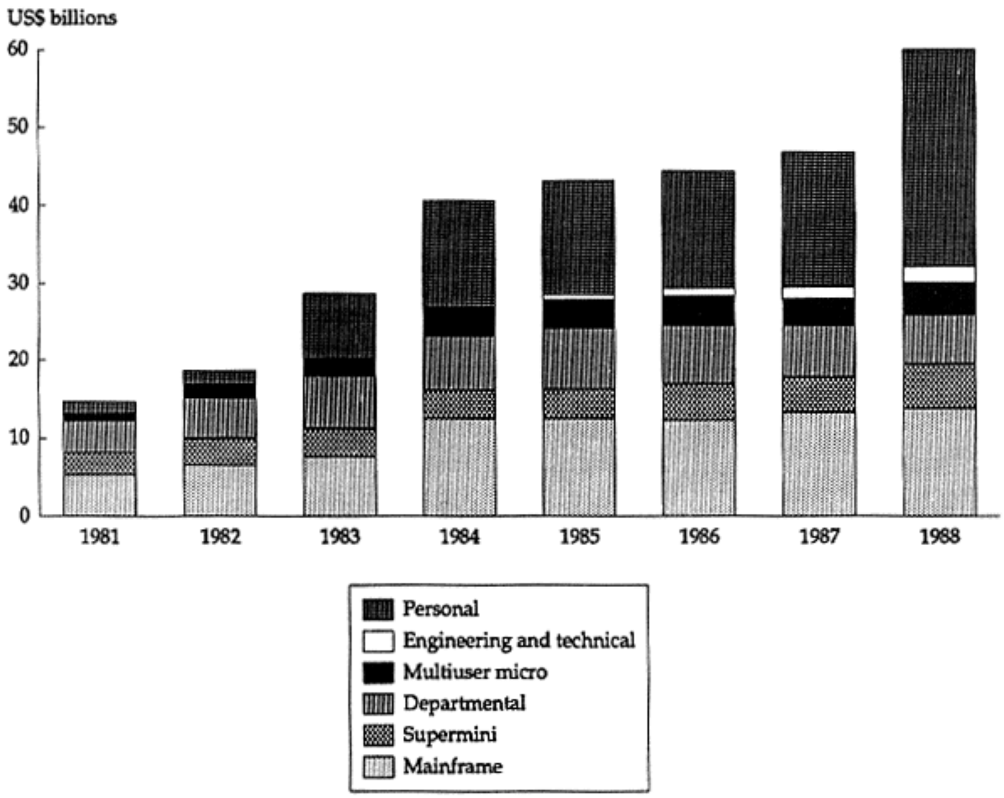

Figure 4.1
Value of Computers Shipped to the U.S. Market, 1981−88
Source: Dataquest, as reported in U.S. Bureau of the Census,
Statistical Abstract of the United States , various years.

with all involved renouncing title to basic concepts; and (c) to the incremental, marginal nature of technical innovation in highly complex systems (as in electronics in general), which had made claims to title and priority difficult to settle. Settlements of government antitrust cases against IBM and AT&T made it much easier for competitors to use technologies developed by these companies. Patents were relegated to a secondary role, largely serving as bargaining chips used in cross−licensing arrangements.

This began to change in the late 1970s. IBM began to copyright its operating system software, and pursued industrial espionage and patent infringement cases against Japanese producers of plugcompatible systems. In the 1980s, cases seeking to establish legal rights to the "look and feel" of a software interface were brought before the U.S. courts. New legislation enabled chip makers to copyright their chip designs. Texas Instruments (TI) appealed to the International Trade Commission to block the importation of dynamic random access memory (DRAM) chips infringing on its patents. The latter threat proved successful, and foreign producers negotiated substantial settlements with TI.11

Whether the increasing visibility of intellectual property issues signals a major change in the rules of the game, or a temporary offensive that ultimately will fizzle, remains to be determined. Clearly, however, the appearance of significant international competition in computers has much to do with the change in the rules. In earlier decades, the relative laxity of the intellectual property regime was irrelevant from the standpoint of the U.S. national interest. Whether one company or another won the battle, the winner was almost certainly going to be a U.S. enterprise. A certain looseness about intellectual property may even have contributed to the rapid diffusion of technology within

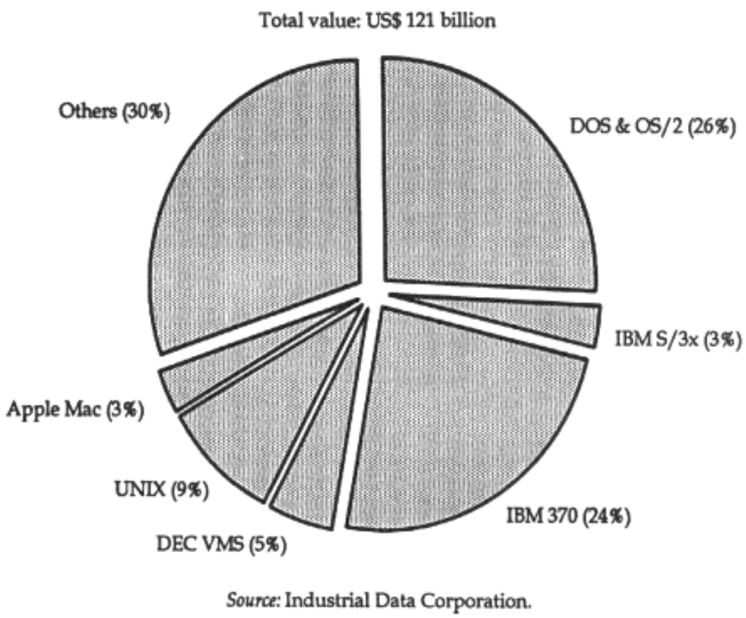

Figure 4.2
Worldwide Computer Shipments, by Operating System, 1988
Source: Industrial Data Corporation

the United States, and to the free−wheeling, entrepreneurial style of the times.

Today, however, the story is very different. Struggles over property rights to innovations reflect not just a distributional struggle between different U.S. interests, but the capture or loss of rents for the national economy. Significantly, major victories have come before the International Trade Commission, a fundamentally political body whose deliberations only affect foreign competitors exporting to the United States. Disputes with other U.S. companies are settled in the Patent Court, in proceedings of a much more protracted and inconclusive nature. The issue of whether or not this is compatible with the General Agreement on Tariffs and Trade (GATT) framework governing international trade has yet to be settled, and the disposition of this issue will have much to do with Whether a fundamentally new sort of regime gets established.

Strategic Alliances

The shift toward international standards within the computer industry in the 1980s—with rival firms cooperating on standards initiatives—coincided with a dramatic rise in other forms of cooperation, particularly international joint ventures and other forms of alliances among firms. Most of these alliances can be classified into one of three categories: joint research and development efforts, ventures designed to integrate new types of systems based on distinct pieces of technology contributed to the joint effort by the cooperating firms, and marketing agreements.

The first two classes of alliance address the potential for the realization of economies of scale and scope in research and development. Joint development projects allow firms to share the costs of R&D required to produce new products. Similarly, firms can combine their proprietary technologies and produce new types of systems at a fraction of the cost and risk that each would separately incur if it attempted to develop the entire system on its own. International tie−ups often avoid some of the domestic antitrust complications that might otherwise arise. Since firms of different nationalities often have marketing networks that emphasize different geographic regions, conflicts that might arise with domestic partners are minimized.

The latter consideration is a major motivation for international tie−ups to market computer products. Also, because computer markets are often surrounded by significant barriers, formal and informal, to foreign vendors, joint ventures are an attractive option for penetrating these markets. The joint venture takes on a national character that enables it to receive preferential treatment in the home markets of all participants.

Implications for NIEs

The vision of competition in computer systems sketched out above leads to some concrete suggestions for policy in a country just entering the game. If one accepts the basic logic, five reasonably simple principles for policy may be suggested.

Maximize Applications of Computers

The most productive task for a nation's computer policy is to put computers to work and collect those social returns. That means maximizing the use and applications of computers. The enormous economic benefits of computer use described earlier are due to steep declines in computer priceperformance being passed on to computer users. The improvement that new technology brings, of course, is not all immediately transferred to users. For some period of time, the innovator earns a profit—a "technological rent"—that provides a return on the initial investment in R&D. But given the actual behavior of computer prices over time, this must be small. Some indicative calculations suggest that only a small portion of the social return—perhaps 10 to 20 percent—is actually captured by the innovator.12 The remainder is immediately "competed away" and passed on directly to the computer user.

As remarked earlier, however, computer use is highly sensitive to computer price, with a price elasticity in the neighborhood of −1.5. This means that policies that raise computer prices can greatly reduce computer use and blunt the increase in productivity that might otherwise be realized. In particular, protectionist policies which attempt to foster the domestic production of hardware will do so at the cost of significant reductions in the extent of application of computers in the national economy. A high price elasticity means that policies that raise cost will greatly reduce the economic benefits. For example, with a constant price elasticity of demand of −1.5, a policy that doubles computer price will reduce computer use by two−thirds. Policymakers should be aware of the substantial welfare costs that such cost−increasing sectoral policies will bring.

Choose a Viable Strategy in Hardware

The heavy R&D investments traditionally required to enter the computer business, and the economies of scale and scope that established producers enjoy in mature markets make it difficult for a newcomer to break into the marketplace. The most successful, tried−and−true formula for entry, historically, has been to introduce a product by targeting a new and growing niche market or application. For a developing country, this probably means choosing an application or niche where special problems, special expertise, or experience gives national companies a special edge. Such applications might include cheap water control systems for rural irrigation applications or rugged and environmentally−hardened systems built to tolerate dust and power glitches.

At the lower end of the product spectrum, the growing significance of nonproprietary standards means that it is now possible to build a simple "commodity" computer using standardized components and a well−defined standard architecture, with little or no R&D investment. Given some intermediate level of engineering and manufacturing know−how, and access to components, one can build such a system. Firms competing in these "commodity" computer markets largely face the problems of a mature manufacturing industry, where relative input prices and factor productivity determine the competitive performance of a producer in world markets. For an NIE with well−honed mass production manufacturing skills, production of these commodity computer products is an entry path into the computer business.

Nonproprietary standards also mean that it is possible to specialize in the design and production of a particular subsystem, which can then be integrated into a computer system conforming to the industry standard, without mastering all the details needed to construct the entire system. A manufacturer can build modems, memory boards, communications software, or special hardware to accelerate scientific calculations without investing great effort in developing the innards of the systems to which these components are to be interfaced. The huge R&D investment traditionally required to enter the computer business is thus much reduced if a firm focuses on the design of a component conforming to the industry standard.

The increasing ubiquity of strategic alliances makes it more likely that relationships can be forged which improve further the chances for both the "commodity" and "subsystem" strategies to work. If a partner company in a large developed country market can offer the marketing and service network that an NIE company lacks, the chances that the product will be a success are further improved.

Software and Systems Integration

As the price of computer hardware has continued to drop, the share in total systems cost of pro−

viding software and configuring the system has risen. In part this is because software production has resisted intensive automation, and remains a highly labor (albeit skilled labor) intensive activity. NIEs with large pools of labor with appropriate training in these skills have an excellent opportunity to break into the computer business through this route, at relatively little cost.

The most profitable activities within computer companies are not selling the hardware; rather, they are providing software and maintenance, and putting together turnkey system "solutions" for computer users' needs. An NIE interested in receiving technological rents from computer systems production might choose to invest in the technological expertise required to undertake these highly profitable activities.

Export or Die

It bears repeating that the relative fixity of R&D costs makes the computer business relentlessly international in scope. The increasing internationalization of the technology also means that a company has to maintain a presence around the world to stay at the leading edge. Historically, no company has ever been able to survive over the long term based only on its position in a sheltered national market.

In the long run, a successful computer company has to sell in foreign markets. For an NIE, this means policies to foster an industry ultimately must make it competitive with foreign competitors, and therefore probably require that it be forced into some degree of competition with foreign competitors in the domestic market. It also means that access to markets in developed countries is essential in the long run, and that deals may have to be cut on other issues—like strengthened protection for intellectual property—which in themselves may be unappealing, but are the price of admission to developed country markets.

People as the Key to Technology Transfer

Perhaps the most important point emerging from the history of the computer industry is the central role that people play in transferring and disseminating technology. The key to gaining access to computer technology is getting one's people on the inside of organizations and institutions with demonstrated capability and expertise.

Trained people are required to take advantage of such opportunities, of course, and investment in educating and training a skilled technical workforce is a prerequisite for such a strategy to work. Investment in technical and educational infrastructure is crucial. Sending people overseas for postgraduate training is a relatively cheap way of both investing in skills and gaining access to the computer technology that can be absorbed within a good university computer science or electrical engineering program. If nationals can then work within high−technology companies in places like Silicon Valley before returning home, absorbing even more relevant technology and bringing it home may be possible.

Similarly, if the local subsidiaries of multinational computer companies can be induced to undertake relatively high−technology activities and train local employees in relevant skills, these local employees can be the conduit of significant technology transfer if they later leave and migrate to a local enterprise or start up their own firm. An NIE may be able to use access to the local market as a bargaining chip to be exchanged for technologically significant activities by a multinational's local subsidiary. However, because computer companies are frequently leery of bringing their best technology into joint ventures where they have minority ownership, restrictions on majority−owned direct foreign investments—as are frequently found in many developing countries—may have to be waived or amended to make this tactic work.

Just ensuring that nationals are working in foreign high−technology companies overseas, studying overseas, or even working in local subsidiaries of high−technology multinationals does not ensure that technology transfer will follow. Gaining access to new technology by getting people inside then requires that they leave and join the interested company on the outside. Incentives may be required to ensure that trained scientists and engineers will ultimately be willing to leave the intellectual stimulation and employment security found in a top industrial R&D facility, and somehow start a local industry from scratch. Some sort of government−venture capital funding may serve both as an incentive for nationals to return and as a mechanism to invest resources in national technical capacity.

The transition and change visible in the computer industry today promise to make it a much more competitive enterprise. The challenge for the NIEs is to put in place policies that allow them to participate in the benefits of the increasing ubiquity and declining cost of computer power.

Notes

1. See D. N. McCloskey, "The Industrial Revolution, 1780−1860: A Survey," in Roderick Floud and Donald

McCloskey, eds., *Tthe Economic History of Britain since 1700, vol. I: 1700−1860* (Cambridge, U.K.: Cambridge University Press), 1981, Tables 6.1 and 6.2.

2. See G. N. von Tunzelman, *Steam Power and British Industrialization to 1860* (Oxford, U.K.: Clarendon Press), 1978, pp. 150−56. Note that the decline in the marginal cost of power exceeded the decline in average cost because of the progressive exhaustion of sources of cheap hydroelectric power.

3. See Kenneth Flamm, *Targeting the Computer: Government Support and International Competition* (Washington: Brookings Institution), 1987, pp. 27−28, for references.

4. See Kenneth Flamm, *Targeting* , pp. 32−35. Large magnitudes are also derived from consumers surplus calculations for the social benefits from technological advance in computers used in the U.S. banking industry. See Timothy F. Bresnahan, "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review* , vol. 76, September 1986, pp. 742−55.

5. See Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology* (Washington: Brookings Institution), 1988, chapter 3.

6. See Kenneth Flamm, *Creating the Computer* , chapter 7.

7. This has also been called the "replacement effect." See Jean Tirole, *The Theory of Industrial Organization* (Cambridge, Mass.: MIT Press), 1988, p. 392.

8. This is exemplified, for example, in the 1988 debate between George Gilder and Charles Ferguson carried on in the pages of the *Harvard Business Review* .

9. For one view of this debate, see Kenneth Flamm and Thomas M. McNaugher, "Rationalizing Technology Investments," in John Steinbruner, ed., *Restructuring American Foreign Policy* (Washington: Brookings Institution), 1988.

10. See Kenneth Flamn, *Targeting the Computer* , pp. 104−105.

11. The sums involved were large. For example, in 1987, TI's pretax profits on its semiconductor business were $346 million, compared with royalty income resulting from its DRAM litigation of $191 million. In 1988, TI made pretax profits of $424 million on semiconductor sales, compared with $124 million on DRAM royalties. See "TI to Cut Workforce; CPUs Double Losses," *Electronic News* , January 30, 1988, p. 37.

12. See Kenneth Flamm, *Targeting the Computer* , p. 38.

5—
Consumer Electronics

Jeffrey A. Hart

The consumer electronics industry is a large member of the family of electronics industries. Consumer electronics products are diverse, ranging from the simplest electronic calculators and watches to the almost professional−quality equipment purchased by audiophiles and videophiles. The Consumer Electronics Show held each year in Las Vegas by the U.S. Electronic Industries Association (EIA) has thousands of exhibitors from dozens of countries. Each year several new product categories are introduced as some entrepreneur finds yet another way to apply microelectronics technology to meet (or create) consumer demand. Table 5.1 is a classification of consumer electronics equipment used by the EIA.

The two main groups of products in the consumer electronics industry are audio and video equipment. In recent years, however, there has been rapid growth in home information systems. An increasing share of consumer electronics sales is in video games and home computers. Further miniaturization of circuitry and displays is making possible a new set of consumer electronics products called personal electronics—such as notebook and palmtop computers—which are relatively inexpensive and highly portable, and bring to the individual consumer capabilities previously available only to larger business customers. Coupled with the development of cellular telephone networks and other wireless communication systems, this is likely to make the market for advanced portable electronics more important at home, at work, and at play. Some of the boundaries between consumer and industrial products are breaking down thanks to the increasing use in both of digital circuitry and their connection to telecommunications networks. It will eventually become necessary to think of the market in terms of the portability of products rather than in terms of the location (e.g., home, factory, office) of their end users.

Audio and video equipment are important sources of high−volume demand for electronics components that are also used in computers and telecommunications equipment. Displays—particularly cathode ray tubes (CRTs) and liquid crystal displays (LCDs)—are necessary components in both televisions and computers, but they are increasingly found in telephones, telecommunications equipment, medical equipment, and military electronic systems. Similarly, many types of semiconductor components are common to all kinds of electronic systems. Although consumer electronics equipment has not always required the same kinds of transistors and integrated circuits that are used in computers and telecommunications equipment, in recent years the types of chips used in both categories of products have begun to converge. For example, one is much more likely to find microprocessors and memory devices (and other forms of digital circuitry) in the current generation of consumer products than in the past.

Market for Consumer Electronics Equipment

The consumer electronics market has been characterized by sustained rapid growth and major shifts of market share among producer regions. The consumer electronics industry in the United States went from a position of global dominance after World War II to extreme weakness. The consumer electronics industry in Europe experienced strong competitive pressures from Asian producers in the 1970s and responded with a combination of highly concentrated ownership, government subsidies for R&D, and barriers to trade and inward investment (including the use of incompatible European stan−

dards). The next round of competition in consumer electronics products is likely to involve a new set of video technologies connected with high−definition television (HDTV). HDTV receivers will differ from the current generation of televisions by improved picture quality achieved through doubling the horizontal and vertical resolution of video images, widening the screen, and high−fidelity digital stereo sound. The market for HDTV products is projected to develop first in Japan, but it will eventually spread to all other regions. The technologies underlying HDTV products will be more closely linked to those necessary for competitiveness in computers and telecommunications equipment than were the technologies underlying the current generation of video equipment. For this reason, the United States and Europe are interested in enhancing their HDTV capabilities and are trying to compensate for their late starts.

Table 5.1
Classification of Consumer Electronics Products

I. Video equipment

A. Color television receivers

B. Monochrome television receivers

C. Projection television

D. LCD or hand−held television

E. Video cassette recorders (VCRs)

F. Color cameras

G. Video disc players

H. Blank video cassettes

II. Audio equipment

A. Audio systems

B. Audio components

C. Home radio

D. Portable audio equipment

E. Car audio

F. Blank audio cassettes

III. Home computers

IV. Video and electronic games

V. Telephones

VI. Calculators and watches

Source: U.S. Electronic Industries Association.

The United States and Europe are the world's two largest markets for consumer electronic equipment. Sales of consumer electronics in the United States increased from about $8 billion in 1977 to around $33 billion in 1990 (see Table 5.2). Sales of televisions, VCRs, and camcorders—the main video products—made up around 29 percent of the total market for consumer electronics in the United States in 1990. The largest segment of this market was color televisions, of which about 21 million units worth $6.4 billion were sold. The market for video cassette recorders (VCRs) at $2.4 billion in 1990 was the third largest segment, after car audio

Table 5.2
Factory Sales of Consumer Electronics Products in the United States, Including Imports, 1977−90
(US$ millions)

Year	*Mono. TVs*	*Color TVs*	*Projection TVs*	*VCRs*	*Video disc players*	*Audio systems*	*Audio components*	*Home radio*	*Portable audio*	*Car audio*	*Audio cassettes*	*Vid cas*
1977	530	3,289	0	180	0	606	1,275	523	1,208	534	0	0
1978	549	3,674	0	326	0	748	1,143	436	1,649	582	0	0
1979	561	3,685	0	389	0	748	1,178	436	1,739	623	0	0
1980	588	4,210	0	621	0	809	1,424	468	1,403	1,368	0	0
1981	505	4,349	287	1,127	55	720	1,363	501	1,157	2,000	227	0
1982	507	4,253	236	1,303	54	573	1,181	530	971	2,100	202	357

1983	465	5,002	268	2,162	81	630	1,268	565	1,102	1,900	234	580
1984	419	5.538	385	3,585	45	976	913	661	1,191	2,500	256	770
1985	328	5565	488	4,738	23	1,372	1,132	379	1,140	2,761	270	1,0
1986	373	6,040	529	3,978	26	1,370	1,358	408	1,389	3,135	300	1,2
1987	341	6,303	527	3,442	26	1,048	1,715	409	1,469	3,523	375	1,0
1988	236	6,277	529	2,848	34	1,225	1,854	377	1,547	3,937	367	936
1989	156	6,530	478	2,625	50	1,217	1,871	379	1,595	4,125	384	923
1990	132	6,376	626	2,439	72	1,270	1,935	360	1,645	4,292	376	948

a . This category includes personal computers and some other items that may be used for business purposes rather than for entertainment. The Electronic Industries Association began to count personal computers only in 1982, which helps accoun in this area.

Source: 1987 Electronic Market Data Book , Washington, D.C., Electronic Industries Association, 1987, p. 6; *1988 Electr* , Washington, D.C., Electronic Industries Association, 1988, p. 6; *The U.S. Consumer Electronics Industry in Review: 199* Washington, D.C., Electronic Industries Association, 1991, p. 9.

systems. As in the United States, the European consumer electronics market comprises mainly video products. About 16 million color televisions, worth $9.5 billion, were sold in 1986. The United Kingdom, France, Germany, and Italy all had purchases of over 2 million units each in 1986. Together, these four countries accounted for 70 percent of the total European market for televisions. In Europe in 1986, 7.2 million VCRs were sold, the total value of which was $5.1 billion, of which the United Kingdom, France, Germany, and Italy accounted for around 70 percent.1

There are major imbalances between the geographical location of production and consumption of consumer electronics equipment. High consumption of televisions and VCRs in the United States and Europe, along with limited local production only of televisions, results in these two largest world markets' being net importers of consumer electronic equipment. The United States has a particularly large trade deficit in consumer electronics. In 1987, for example, the United States imported $13.6 billion more than it exported in consumer electronics, up from $7..9 billion in 1983.2 Of the 10 million VCRs sold in the United States in 1990, over 90 percent were imported directly, mainly from Japan and the Republic of Korea. Less than 10 percent were assembled from imported parts. Since larger televisions are increasingly assembled or manufactured in the United States, the largest part of the U.S. trade deficit in consumer electronics is attributable to imports of VCRs.3 The U.S. trade deficit in consumer electronics declined to around $10 billion in 1989 and 1990, thanks to increased local manufacturing of previously imported products, mainly televisions. Japan had an overall surplus in consumer electronics of about 2.5 trillion yen in 1990 (see Table 5.3). The United States is by far the most important single destination for Japanese exports.4 However, Japanese exports of consumer electronics were hurt by the revaluation of the yen in 1985; they dropped from 3.5 trillion yen in 1985 around 2.2 trillion yen in 1988, but partly recovered to 2.6 trillion by 1990. Since imports were almost negligible in Japan, even with the recent growth of imports from Southeast Asia, the trade surplus also dropped between 1985 and 1988 by about 1.3 trillion yen (see Table 5.3).

Production of Consumer Electronics Equipment

World production of consumer electronics equipment totaled $63 billion in 1990. This represents around 11 percent of world production in electronics in general (see Tables 5.4 and 5.5).5 Consumer electronics production grew at an average rate of 10.6 percent per year between 1985 and 1990, but slowed down in 1989−90. Japan had the largest share of global consumer electronics production—around 49 percent in 1990. Newly industrialized economies (NIEs) in Western Europe and Asia had roughly equal shares, around 20 percent each, in that year. The United States produced a little over 10 percent of the global total of consumer electronics equipment (see Table 5.5).

Of the world's 10 largest producers of color televisions in the early 1980s, 5 were Japanese (see Table 5.6). Philips was the world's largest single producer in 1982, but Matsushita was a very close second. Philips owns 25 percent of Grundig and since 1985 has controlled that firm. The purchase of GE/RCA by Thomson in 1988 made Thomson's total production approximately equal to that of the third ranked firm—Sony. Zenith was the only U.S. firm in the top 10 in 1982. With the closure of its U.S. assembly operations in the United States in 1992, Zenith became dependent on its Mexican operations and on an alliance with Lucky Goldstar of Korea to maintain its share of world markets.

Declining Production in the United States

The U.S. consumer electronics industry, which had led the world into the radio and television ages, is now only a shadow of its former self. This

Table 5.3
Balance of Trade in Consumer Electronics, Japan, 1987−90
(yen trillions)

Year	*Exports*	*Imports*	*Balance*
1978	1.352	0.021	1.331
1979	1.480	0.037	1.443
1980	2.047	0.038	2.009
1981	2.600	0.033	2.567
1982	2.620	0.026	2.594
1983	2.829	0.020	2.809
1984	3.495	0.023	3.472
1985	3.805	0.024	3.781
1986	2.940	0.032	2.908
1987	2.317	0.061	2.256
1988	2.208	0.098	2.118
1989	2.287	0.145	2.142
1990	2.618	0.113	2.505

Source: Facts and Figures '88 , Tokyo Electronic Industries Association of Japan, 1988, pp. 36−45; *Facts and Figures '91* , Tokyo, Electronic Industries Association of Japan, 1991, pp. 42−43, and 46−47.

Table 5.4
Total Electronics Production by Selected Region, 1984−90
(US$ billions)

Region	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
United States	169	166	175	190	201	205	211
Japan	71	75	108	129	166	165	165
Western Europe	79	87	116	140	150	151	155
Newly industrialized economies	16	21	27	38	49	57	60
Total	335	349	426	497	566	578	591

Source: Facts and Figures on the Japanese Electronics Industry , Tokyo, Electronic Industries Associaton of Japan, 1988, p. 17; *Facts and Figures '91* , Tokyo, Electronic Industries Association of Japan, 1991, p. 115.

Table 5.5
Consumer Electronics Production by Selected Region, 1984−90
(US$ billions)

Region	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
United States	6.4	5.7	6.3	6.1	7.2	6.2	6.4
Japan	19.9	20.4	26.1	27.2	33.2	20.5	30.6
Western Europe	7.0	7.1	10.1	12.1	12.5	12.1	12.3
Newly industrialized economies	−	6.0	7.7	10.6	12.9	13.3	13.6
Total	−	39.2	50.2	56.0	65.8	62.1	62.9

− Not available.

Source : Same as Table 5.4.

Table 5.6
Top Ten Producers of Color TVs Worldwide, 1982

Firm	*Country*	*Production (thousands)*
Philips	Netherlands	4,600
Matsushita	Japan	4,500
Sony	Japan	3,400
Toshiba	Japan	2,800
Hitachi	Japan	2,500
RCA	United States	1,800
Zenith	United States	1,800
Thomson	France	1,700

Sanyo	Japan	1,600
Grundig	Germany	1,600

Source: BIS−Mackintosh as cited in Jacques Pelkmans and Rita Beuter, "Standardization and Competitiveness: Private and Public Strategies in the EC Colour TV Industry," paper prepared for the INSEAD symposium, Product Standardization as a Tool of Competitive Strategy, June 9−10, 1986, p. 26.

can be attributed largely to a failure in the managerial vision of U.S. firms. In particular, U.S. firms' analysis of the Japanese threat in consumer electronics focused too much on labor costs and not enough on the incorporation of new technologies. U.S. television firms tried to get around their high labor costs by manufacturing in low−wage countries. While this was rational in the short run, it put the firms on a technological trajectory that was disastrous in the long run. U.S. firms also failed to see the importance of new component technologies in television, and did not recognize in time the market potential of VCRs. Besides greater reliability and lower production costs that were at the root of the increased Japanese global competitiveness in consumer electronics, Japanese trade and investment barriers, along with weak enforcement of trade laws by the U.S. government speeded the decline of the U.S. industry. Japanese firms engaged to some degree in dumping consumer electronics products on U.S. markets from the early days of their entry. Japanese markets were closed to U.S. producers by high tariff and nontariff barriers during this period, and no U.S.−owned television firm was permitted to establish a manufacturing presence in Japan.

The Demise of U.S. Television Manufacturing

At the beginning of the 1950s, there were 140 firms in the U.S television manufacturing industry; only 50 remained by 1956, 27 by 1960, and 5 by 1980.6 The number of workers in the industry declined from a high of 100,000 in 1966 to 33,000 in 1984.7 As of 1986, only three U.S.−owned firms—Zenith, RCA, and Curtis Mathes—manufactured televisions in the United States. In 1987, RCA's television manufacturing facilities were acquired by General Electric (GE) and then sold in January 1988 to Thomson, a French firm. By the late 1980s, the only remaining U.S.−owned television manufacturing was Zenith (see Table 5.7). In the late 1980s, Zenith operated its television manufacturing operations at a loss, because of low prices in the industry as a whole. Thomson suffered financial losses in the U.S. market for the same reason. Zenith sold its more profitable computer business (Zenith Data Systems) to Groupe Bull of France in 1990 in order to stay in the television business. It solicited new investments in 1991 from a Korean firm, Lucky Goldstar, to ward off a hostile buy−out by a New Jersey−based air conditioner company. In 1992, Zenith closed its U.S. plants and relied entirely on its factories in Mexico. It has entered an alliance with AT&T to develop a viable HDTV system for the United States. If Zenith's HDTV efforts fail to result in renewed profitability in the next three to four years, the firm will probably be sold or liquidated.

Some of the relative decline of the U.S. television industry can be attributed to a shift in production to low−wage developing countries. This is particularly true of lower−priced audio equipment and televisions. In the late 1960s, most of the major U.S. television manufacturers began to locate plants for final assembly in low−wage countries in Asia and Latin America (mainly in Mexico). Firms that established assembly plants overseas for production of exports to the United States did not have to pay export duties on parts sent to those plants and only paid U.S. import duties on the value added abroad. All production of monochrome receivers was soon relocated offshore, while production of color receivers remained, for the most part, in the United States. The offshore products were converted more quickly to semiconductor components than the domestic products, creating expertise in manufacturing transistorized televisions in the wrong (from the U.S. viewpoint) places. Moreover, heavy reliance on offshore assembly led to slow introduction of automated insertion equipment and single−board chassis. The offshore operations, mainly in Mexico and East Asia, were at the time not considered sufficiently reliable for single−board chassis assembly.

Table 5.7
The Fifteen Top Television Brands in the U.S. Color TV Market, 1989

Firm	*Market share (percentage)*
RCA (Thomson)	16.3
Zenith	12.0
Magnavox (Philips)	6.4
Sony	6.4
General Electric (Thomson)	5.6
Soars, XLI	5.0
Sharp	4.8
Mitsubishi	3.6
Emerson	3.5
Toshiba	3.5
Sylvania (Philips)	3.3
Panasonic	3.2
Montgomery Ward	2.5
Hitachi	2.5
Goldstar	2.1

Note: Sears and Montgomery Ward purchase televisions mainly from Asia and European producers and then put their own brand names on them.

Source: Television Digest as cited in *The New York Times* , March 10, 1990, p. 17.

The largest single source of television exports to the United States in 1990 was Mexico. Most of these exports came from the *maquiladora* plants in Northern Mexico. Under Mexican law, firms that assemble products solely for export do not have to pay import duties. Under the U.S. tariff code, firms that establish plants overseas for production of exports to the United States do not have to pay export duties and pay only import duties on the value added abroad. Accordingly, all the major firms involved in supplying consumer electronics products to the United States have located assembly plants below the border with Mexico to take advantage of U.S. and Mexican laws. The main incentive for doing this is to reduce direct labor costs in the assembly phase of manufacturing. In 1987, there were about 1,250 *maquiladoras* employing 330,000 workers.[8] Only 30 of these were owned by Japanese firms, but about 19 percent of all *maquiladora* workers were employed by those firms.[9] Zenith has a large *maquiladora* , which produced around 60 percent of all the televisions it sold in the United States. After the closure of its assembly plants in the United States in 1992, Zenith's Mexican facility will be assembling all the televisions it sells in the United States. Both Philips and Thomson also have Mexican plants, but the domestic content of their products (domestic over total value added) is actually higher than Zenith's.[10] The *maquiladora* system not only allows the consumer electronics firms to reduce their as−

sembly costs, it is a useful way of reminding U.S. workers of the need to keep their productivity high in order to justify their higher wages.

These movements, however, have been to some extent offset by foreign companies setting up television plants and R&D in the United States. Although only a little more than 12 percent of the total television market is supplied by U.S.−owned firms, approximately 70 percent of the value of televisions sold on the U.S. market is estimated to be domestic in origin. The reason is that most foreign firms have set up plants in the United States to manufacture picture tubes and cabinets and to assemble televisions locally. The tube and the cabinet combined with the local labor costs are the main contributors to the domestic content of televisions sold in the United States. The circuitry in televisions contributes only about 5 to 7 percent of the manufacturing costs of an average television. Very little of this circuitry is produced in the United States. U.S. final assembly operations were established by the major Japanese producers in the following sequence: Sony in 1972, Matsushita in 1974, Sanyo in 1976, Mitsubishi in 1977, Toshiba in 1978, and Hitachi and Sharp in 1980. With the exception of Matsushita's purchase of Motorola's Quasar division in 1974, all the Japanese facilities are new ones. The Korean firm, Lucky Goldstar, built an assembly plant in California in 1981. Philips and Thomson established their presence in the United States mainly through acquisitions of U.S. firms. Philips purchased Magnavox in 1975 and Sylvania in 1981. Thomson bought RCA/GE consumer electronics from GE in 1988. Thus, every major supplier of consumer electronics to the United States has at least an assembly operation in the United States. Some—like Philips and Thomson—have a major research facility, as well as components manufacturing operations. Of the Japanese firms, only Sony has invested in a major R&D facility for consumer electronics in the United States.

The main challenge to the U.S. television industry, however, has not been from low−wage countries, rather mainly from Japan, whose share of consumer electronics production in 1990 was 49 percent (see Table 5.4). Of the top 10 firms producing color televisions in the early 1980s, 5 were Japanese (see Table 5.6).11 Japan also leads in production of higher−priced televisions, VCRs, and camcorders.

The success of Japanese televisions in the U.S. (and other) markets is the result of technological and marketing strategies on the part of Japanese firms, along with some predatory pricing (documented in a series of successful but unenforced antidumping petitions).12 Of primary importance was the early replacement of vacuum tubes with semiconductors. Sony Corporation sold the first all−transistor monochrome television in 1959. Soon after, all the larger Japanese electronics firms (Matsushita, Mitsubishi, Hitachi, Toshiba, Sharp, and Sanyo) introduced transistorized monochrome receivers. A U.S. manufacturer, Motorola, developed the first prototype solid−state color television in 1966, but Hitachi was the first to produce a commercial solid−state color television in 1969. By 1970, 90 percent of all color televisions produced in Japan were solid−state.13 Semiconductor technology was more amenable than vacuum tubes to automation of assembly. Development of devices for automatically aligning and inserting semiconductor components on circuit boards was pioneered by Japanese firms in the late 1960s. The first generation of such equipment was operating by 1968, and it was manually rather than automatically controlled. A second generation was produced in 1972 that was much faster, but was still controlled manually. The third generation was about 10 times faster than the first generation and allowed for limited numerical or computer control of the insertion process.14 In a related development, large−scale integrated (LSI) circuit technology allowed semiconductor manufacturers to put more transistors on a single device, and Japanese television producers were able to substantially reduce the number of parts and circuit boards per television set. For example, it was only in the mid−1980s that General Electric was able to put the circuitry for its color televisions on a single board, whereas Japanese firms had been doing so since 1976. The switch to single−board chassis further reduced the labor time required for assembly.15

Japanese firms began to market televisions in the United States in the early 1960s, but they mainly confined sales to smaller units (with screens smaller than 19 inches) sold through department stores or large electronics retailers rather than through licensed distributors. At first, these sets sold because they were simply cheaper than their U.S.−made counterparts. However, they used tubes and the circuit designs were inferior to U.S. products. Soon, however, tubes were replaced first with transistors and then with integrated circuits, circuit designs continuously improved, and televisions became more reliable and required less maintenance and servicing. During the mid−1970s, for example, U.S.−made color televisions were failing at five times the Japanese rate.16 By 1977, the number of faults discovered in production were 1.4 to 2.0 per set in the United States and only .01 to .03 in Japan.17

The greater reliability and durability of Japanese sets made it possible to sell them widely without building an extensive service network. The service networks of the U.S. manufacturers were thus converted from a barrier to entry for foreign firms to a financial liability. U.S. firms spent a considerable effort maintaining the distributor networks in the belief that their main customers would continue to demand larger sets with higher−quality pictures, which would necessarily require more servicing than their Japanese or East Asian competitors were offering, that consumers did not care about semiconductor componentry as much as they cared about the size and quality of the picture, and that semiconductors would not be as reliable as tubes. U.S. firms, therefore, kept color television production in the United States after they moved black−and−white television production offshore, and they were slow to introduce semiconductor components and to reduce the number of circuit boards, and they underestimated the ability of Japanese firms to produce televisions with semiconductor components and to move up from simple black−and−white sets to small color sets and finally to larger color sets. In this respect, they resembled their colleagues in the automobile industry who were willing to concede the market for low−priced subcompact vehicles to Japanese competitors in the belief that they would continue to have production−cost and distribution advantages in high−priced vehicles. But in actuality, Japanese firms quickly applied the lessons they learned in competing in the low−end markets to higher−end products, while U.S. firms were cutting themselves off from this important source of learning.

The Stillbirth of the U.S. Video Recorder Industry

Despite the mistakes made in television production, the U.S. consumer electronics industry might still have been able to hang on, had a few U.S. firms been able to shift their activities from television to VCR production in the 1970s. The story of Ampex Corporation illustrates how this did not happen.18 Ampex owned all of the patents required for producing video recorders and used those patents to dominate the markets for professional video recording equipment sold mainly to television broadcasting stations, but it was unable to turn that technological advantage into a commercial one in the vast consumer market for VCRs that arose in the 1980s.

Like many other U.S. firms, Ampex attempted to get around patent and marketing problems in Japan by forming a joint venture in 1960 with a Japanese firm, Sony. Sony would produce a portable version of the Ampex professional recorder in exchange for Japanese production of Ampex recorders for nonbroadcasting customers. This venture was of only limited success, especially after Sony introduced a transistorized recorder of its own in 1961. In 1968, Ampex management decided to make a strategic shift toward producing a video recorder for the consumer market, scrapping the development of a new professional video recorder, the VR−7700, in favor of a consumer−oriented machine called the "Instacorder" which used half−inch tape, and was compact, easy−to−use, and self−loading. While the engineers in California and Illinois developed a prototype, a number of business arrangements for financing and marketing the product were attempted. Toamco, a joint venture between Ampex and Toshiba, was formed in 1964 to manufacture Ampex−designed professional tape recorders and computer tape units that were sold by Toshiba in Japan and by Ampex elsewhere. Toamco was not doing well financially in the late 1960s and was given the task of producing the Instavideo. This decision was governed by concerns over cash and engineering personnel shortages in Ampex, by the desire to avoid a deal with a U.S. firm that could become a domestic competitor, and by the need to produce a machine that was compatible with the emerging standard for video recording tape, a half−inch format called the EIAJ−Type 1, which had been pioneered by the Japanese.19

The first Instavideo machine was demonstrated at the Americana Hotel in New York on September 2, 1970. The machine used an automatic−loading cartridge system—rather than a cassette—with a tape capacity of 60 minutes extended play. It weighed less than 16 pounds, and included a monochrome television camera. The tape was compatible with the EIAJ−Type 1 standard. The unit with camera was priced at $1,500, without at $1,000. The demonstration was a smashing success. Ampex stock increased in value by 45 percent and the firm was able to use the enthusiasm after its new product announcement to ward off financial difficulties for a few more months.[20]

By the beginning of 1971, however, Toamco was having difficulties producing the Instavideo, while Ampex was experiencing severe financial difficulties. In addition, Matsushita had marketed a cheaper video recorder at about that time, taking some of the luster off the Ampex Instavideo announcement. Also, sales of Ampex magnetic tape and consumer audio equipment plummeted as cheaper imports had come onto the market. Ampex became overly dependent on debt capital to finance some of its acquisitions, and by the end of 1971 it reported a loss of $12 million, which rose to $90 million in 1972. In order to restore the firm

to fiscal soundness, management cut back Ampex's expenditures and investments. One of the projects that was cut was the Instavideo project, which ended the chances for any U.S.−owned firm to participate in the breathtaking growth of the home video recorder market.

The inability of Ampex to commercialize its lead in video recorder technology, therefore, was primarily a function of poor management leading to financial weakness. The joint venture with Toshiba hastened the diffusion of U.S. VCR technology to Japan. Reportedly, Ampex was approached by Magnavox before it decided to go with the joint venture with Toshiba, but it decided in favor of the Toshiba deal because it thought that the Japanese firm was less likely to be a serious competitor in the future.[21] Larger U.S. firms, such as RCA, GE, or Zenith, apparently did not have the vision to see the future of VCR markets and did not attempt to acquire Ampex or to salvage the Instavideo project by purchasing the VCR technology. The subsequent failed efforts of RCA to market a video disc system suggest that even by the late 1970s the large U.S. consumer electronics firms had not developed a proper understanding of the nature of consumer demand for home videotape systems. GE apparently did not perceive a great future for its consumer electronics operations. Japan's earlier successes in cameras and optical equipment, together with its growing strength in VCRs, paved the way for success in video cameras and projection televisions in the 1980s.

Impact of the Decline of the U.S. Consumer Electronics Industry on U.S. Competitiveness in Electronics

The decline of the U.S. television industry hurt the ability of U.S. firms to compete in follow−on products like VCRs and video cameras. In addition, the loss of the consumer electronics industry eventually handicapped the U.S. semiconductor industry in its efforts to compete with Japanese firms. Semiconductor producers in the U.S. were not able to keep up with the state of the art in high−volume composite metal oxide on silicon (CMOS) process technology, nor were they able to match the developments in optoelectronics (and particularly CCDs or charge−coupled devices), liquid crystal displays (LCDs), and consumer−oriented analog circuitry.[22]

One important result of the failure of U.S. consumer electronics was to reduce the proportional importance of consumer demand in total demand for semiconductors. Whereas consumer end use accounted for more than 40 percent of total consumption of semiconductors in Japan in 1988, the same figure for the United States was around 7 percent.[23] To the extent that the structure of consumption of semiconductors in Japan differs radically from that of the United States, it remains difficult for U.S. firms—which have specialized in products for the computer, telecommunications, industrial, and automotive markets—to penetrate Japanese markets. Japanese firms have used this fact to explain why U.S. penetration of the Japanese semiconductor market has remained lower than 15 percent, despite a 30 to 40 percent share of the European market.[24]

The current generation of consumer−oriented semiconductors are quite different from the semiconductors used in computers, telecommunications, or other end uses. They tend to involve analog rather than digital circuitry. Digital techniques are increasingly important in consumer electronics, however, so the gap between consumer and nonconsumer componentry is rapidly decreasing. Portable consumer electronics products use integrated circuits that dissipate less electrical power, such as CMOS devices. CMOS−based consumer products can be battery−operated and very compact. The Japanese dominance of consumer markets, therefore, has contributed to their dominance of markets for CMOS semiconductors and downstream products like laptop computers, which depend heavily on CMOS technology.25

Another example was the growth in demand for hand−held LCD televisions. In 1984, only 32,000 LCD televisions were sold in the United States. By 1986, 771,000 LCD televisions were sold in the United States, all of them imported from Japan. In 1986, Japanese firms produced over 1.7 million LCD televisions. They had been able to descend their learning curves for production of LCDs so quickly that it was difficult for their foreign competitors to enter the market for LCD televisions. LCDs are used also in laptop computers, so it was harder for many U.S. computer firms to enter laptop markets successfully because they had to purchase LCDs from Japanese competitors (or at least from potential competitors).26

Weakness in U.S. consumer electronics production has had other repercussions besides reducing the volume of domestic demand for electronic components like CMOS integrated circuits and LCDs. By exiting consumer markets, U.S. electronics firms missed an important opportunity to learn how to implement new production methods for high−volume production of electronic systems. High−volume consumer electronics production in Japan has driven innovations not only in automated insertion for assembly of printed circuit boards, but also in successor technologies like sur−

face−mount technology (SMT), tape−automated bonding (TAB), amorphous and polysilicon processing, and chip−on−glass (COG) technology.27

Emergence of Japan as a Major Producer

Driven by technological innovation and successful market strategies discussed above, Japanese production of consumer electronic equipment rose dramatically between 1967 and 1990 (see Table 5.8). In 1967, Japan produced 1.3 million color televisions. Production of color televisions peaked in 1985 at 17.9 million units, but fell back to around 14 million in the next two years.28 Because Japanese firms were able to dominate VCR and audio equipment markets in the 1980s, they were able to increase overall production of consumer electronics even though the production for televisions stabilized. VCR production in terms of value first exceeded production of televisions in 1981. By 1987, VCR production was almost twice the value of television production. VCR production began to drop off in value in the mid−1980s, despite the fact that volume continued to increase. The average selling price of VCRs declined substantially in the mid− to late 1980s, thanks partly to increased competition from the Asian NIEs. Overall production of consumer electronics continued to increase slowly in the 1985−87 period, but exports declined and imports rose after 1986. New video equipment (camcorders, projection televisions, and other items) partially compensated for the decline in volume of sales of audio equipment, televisions, and VCRs.

Table 5.8
Production of Consumer Electronics Equipment in Japan, 1967−90
(yen billions)

Year	*TVs*	*VCRs*	*Total*
1967	133.2	0	133.2
1968	278.6	0	278.6
1969	503.7	0	503.7

1970	681.3	0	681.3
1971	608.2	0	608.2
1972	715.0	0	715.0
1973	686.2	0	686.2
1974	615.1	0	615.1
1975	584.5	0	584.5
1976	768.1	0	768.1
1977	700.8	0	700.8
1978	617.3	204.1	821.4
1979	640.8	296.2	937.0
1980	711.9	562.8	1,274.7
1981	739.0	1,086.8	1,825.8
1982	683.1	1,285.0	1,968.1
1983	684.6	1,514.0	2,198.6
1984	755.8	2,090.0	2,845.8
1985	897.1	1,889.2	2,786.3
1986	723.8	1,659.4	2,383.2
1987	765.1	1,241.5	2,006.6
1988	814.1	1,212.0	2.026.1
1989	819.3	1,134.6	1,953.9
1990	874.6	1,078.5	1,953.1

Source: Facts and Figures , Tokyo, Electronic Industries Association of Japan, 1988 and 1991.

The largest producers of consumer electronic equipment in Japan are Matsushita, Sony, Toshiba, Sanyo, Sharp, Mitsubishi, NEC, and Hitachi. All these firms, with the possible exception of Sony, are vertically integrated electronics companies with ties to larger units called *keiretsu* , groups of firms clustered around a leading bank. They all produce a significant proportion of the semiconductor components used in their own consumer products. Japanese strength in semiconductors has been an important reason for the continued growth of their consumer electronics business. All the major firms, again with the exception of Sony, are quite diversified.

European Production

Despite similar patterns of overall production and consumption, a major difference between Europe and the United States is that the major European consumer electronics firms were able to survive in the presence of Asian competition. Only 14 percent of the European market for color televisions was supplied by Japanese firms in 1976. Tables 5.9 and 5.10 list the main European producers of color televisions and VCRs.

The European consumer electronics industry survived primarily on the basis of extensive government assistance in various forms, including R&D subsidies, the promotion of mergers and acquisitions, the granting of exclusive patent rights for European standards, and a variety of trade and investment barriers to keep out Asian competitors.29 The two most important European firms—Philips and Thomson—produced a substantial number of televisions and VCRs in Europe and in North America. Their strategy included a strong commitment to local production in North America as part of a global defense against Asian competition. Philips purchased two large U.S. television firms: Magnavox in 1975 and Sylvania in 1981. Thomson purchased the consumer electronics operations of RCA/GE in 1987, which made it

the number one producer of televisions in the United States. Thomson marketed and assembled Japanese−designed VCRs for Europe and North America; only Philips had the capability to manufacture its own VCR designs as of the late 1980s.

Table 5.9
Western European Color TV Production, 1986

Firm	*Production (thousands)*
Philips	3,100
Thomson	2,000
Grundig	1,950
lit	1,305
Nokia	1,000
Thorn−EMI−Ferguson	800
Salora/Luxor	680
Blaupunkt	600
Sony	535
Sanyo	410
Hitachi	370
Toshiba	310
Matsushita	310
Other Japanese	130
Other Asian	410
Other European	2,295
Total	15,195

Note: Philips assumed managerial control over Grundig in 1985 and Thomson acquired Thorn−EMI−Ferguson in 1987.

Source: BIS−Mackintosh as cited in Alan Cawson, "Sectoral Governance in Consumer Electronics in Britain and France," paper prepared for a conference on Comparing Capitalist Economies, Racine, Wisconsin, May 4−6, 1988; Nokia, *Annual Report* , 1987.

Table 5.10
Western European Video Cassette Recorder Production, 1986

Firm	*Production (thousands)*
Philips	800
Grundig	750
JVC−Thomson	750
Hitachi	450
Matsushita−Bosch	335
Sanyo−Fisher	240
Mitsubishi	165
Sharp	160
Toshiba	160
ITT	150
Others	240
Total	4,200

Source: Same as Table 5.9.

The Japanese firms were kept out of the European television market in earlier times by restrictions on the licensing of patents for PAL and SECAM technologies. More recently Japanese firms have avoided local production of televisions because the Europeans made it clear that they would not permit Japanese television plants in Europe to service the not−yet−completed internal market. That is, no Japanese producer could be sure that products assembled, say, in the United Kingdom would be considered sufficiently European to be exported freely to, say, France. Since it was possible to make money by exporting and licensing the production of VCRs and camcorders, the Japanese firms focused their European activities in these areas.30 European firms, accordingly, are weaker in VCR and camcorder markets than they are in televisions. Japanese firms supply about 40 percent of the European VCR market. Other than Philips, which developed its own VCR technologies in collaboration with Sony, the European firms all have to produce VCRs under joint ventures with Japanese firms. Examples are JVC−Thomson, Matsushita−Bosch, Amstrad−Funai, and Hinari−Shintom.

Production in the Asian NIEs

The reduced trade surplus in Japanese consumer electronics in the late 1980s was due mostly to increased competition from producers in Asia, especially in Korea, Taiwan (China), and Singapore. The largest increase in Japanese imports from Asia between 1985 and 1987 was in audio cassette recorders, but increases also occurred in color televisions and VCRs. Most of the production in Asian newly industrialized economies (NIEs) for export to Japan is by subsidiaries of Japanese firms or by local makers under OEM contracts.31 Exports to the rest of the world, however, are not so closely tied to Japanese ownership or contractual arrangements. The Asian NIEs are globally competitive in low−end consumer electronics products. They combined favorable labor market conditions (high skill base and relatively low wages) with successful transfer and adaptation of semiconductor and electronics assembly technologies from Japan and the United States to get where they are today. As they come under competitive pressure from lower−wage countries in Asia and elsewhere, the Asian NIEs are moving up−market into more sophisticated and more expensive products, thus increasing the pressure on Japan to promote new generations of consumer products like HDTV.

The three largest Korean firms—Lucky Goldstar, Samsung, and Daewoo—produce their own designs under their own labels, unlike the

smaller electronics firms of Hong Kong and Taiwan (China). Each of these firms has its own semiconductor operations. They all produce their own CRTs for televisions and computer monitors. Korea is beginning to move its product mix up toward the high end. The Koreans, for example, have begun their own program to develop HDTV technologies funded at around $200 million. The two largest firms in Taiwan (China)—Tatung and Sampo—manufacture color televisions. Tatung began manufacturing VCRs in 1982. The electronics strategy of Taiwan (China) is focused more on information technology than on consumer electronics. Hong Kong, in contrast, has focused on the production of small consumer items like portable black−and−white televisions, portable radios and audio cassette recorders, hand−held video games, and the like. Hong Kong producers tend to be small firms working under contract with larger distributors. The People's Republic of China (PRC) is quite interested in becoming a major producer of consumer electronics. The opening of PRC markets to international trade produced initially a major influx of consumer items from Japan and other Asian economies. In 1987 Philips negotiated a joint venture with Novel of Hong Kong and China National Huadong of the PRC to produce 1.6 million color television tubes per year in Jiangsu province. Philips is also working with the PRC on joint ventures for VCRs and bipolar integrated circuits.[32]

The success of the Asian NIEs in becoming internationally competitive in low−end consumer electronics has resulted in a number of attempts by the Western developed countries to erect new barriers to imports. A series of antidumping cases has been brought against Asian NIEs in the United States and the European Community, some of them resulting in the imposition of dumping duties, "voluntary" export restraints, and quotas. The continued access of Asian NIEs to the markets of the wealthy countries cannot be guaranteed, given the current sensitivity of the United States and Europe to their weaknesses in electronics vis−a−vis Japan. Thus, the Asian economies are likely to turn to other regions for outlets for their products. The Asian NIEs, like Japan, are also likely to substitute local production (via investments in overseas plants) for exports of televisions and VCRs in major developed markets.

The Role of HDTV in Future Consumer Electronics Markets

The competitive pressure from the Asian NIEs in low−end consumer electronics is pushing Japanese and European firms to move up−market. Firms in Korea and Taiwan (China) are also moving upmarket to deal with the competitive pressures from even lower−wage economies (e.g., Malaysia, Thailand, the Philippines). The response of Japan has been to push for a new generation of audio and video products centered around the concept of HDTV. HDTV is defined in engineering terms as a video experience in which at a viewing distance of three times the height of the display the viewer cannot distinguish between the video image and reality. In practice, however, HDTV is defined in terms of three changes in the current television systems: (a) sharper picture resolution, (b) wider screens, and (c) digital stereo sound. For a new display to be considered an HDTV display, it must have about twice the horizontal and vertical resolution of the U.S. NTSC (National Television Systems Committee) maximum theoretical resolution of 360 by 360 pixels (or picture elements). The screen of HDTV displays will be more elongated with aspect (width to height) ratio of 16 to 9 in contrast with the current aspect ratio of 4 to 3. Digital stereo sound is the type of high−quality sound available on contemporary compact disc (CD) and digital audio tape (DAT) players.

Japan is well in the lead in developing HDTV technologies. The public broadcasting company, NHK (Nippon Hoso Kyokai), has played a central role in this. NHK Laboratories began work on high−definition systems in 1970, and was initially motivated by a desire to overtake the Europeans. The two major European color television standards, PAL and SECAM, permit a somewhat higher degree of picture resolution than is possible with NTSC (the standard that prevails in the United States and most of Asia). NHK believed that a move to higher resolutions was inevitable and wanted to anticipate any such move on the part of the Europeans. Since 1970, NHK and the major Japanese manufacturers have spent approximately $700 million on the development of HDTV technologies. By 1980, they had worked out a transmission system based on a bandwidth compression technique called MUSE (for Multiple Sub−Nyquist Sampling Encoding). In 1984, Japanese transmission equipment manufacturers officially adopted MUSE and embedded it in a set of HDTV standards called "Hi−Vision."

The Hi−Vision production standard calls for an image with 1,125 horizontal lines scanned at a rate of 60 fields per second.33 For this reason, the Hi−Vision production standard is referred to as the 1125/60 standard. There are also Hi−Vision standards for video tape equipment, editing equipment, broadcasting equipment, and receivers, which all have to be compatible with one another. NHK has been the linchpin for negotiating or imposing these standards on the manufacturers and

private broadcasters. NHK has the ability to do this because it owns most of the key technologies for Hi−Vision HDTV as well as transponders on the broadcasting satellites that can provide HDTV delivery.

NHK initiated broadcasts of Hi−Vision HDTV via direct broadcast satellite (DBS) in 1989. The initial broadcasts were only for one hour per day. These broadcasts were increased to three to four hours per clay in 1991 with the launching of a new satellite, the BS3b. NHK wanted the Hi−Vision standard to be adopted outside Japan so that it would be less expensive to convert foreign programs for Japanese broadcasting and to adapt Japanese equipment for foreign markets. So they set about the task of getting broader acceptance for Hi−Vision as a world standard for HDTV.

The Sixteenth Plenary Assembly of the Consultative Committee on International Radio (CCIR) of the International Telecommunication Union (ITU) met in Dubrovnik, (former) Yugoslavia, from May 12−24, 1986. At this meeting, the United States, CBS, Japan, Canada, and the North American National Broadcasters Association (NANBA) proposed that the Japanese 1125/60 production standard be adopted as a global standard. This proposal was firmly opposed by the European Community countries. The Europeans Fproposed further study of the matter as a delaying tactic and rejected a compromise proposal from the United States, which would have resulted in a *de facto* standardization of production equipment.

The European Approach to HDTV

The Europeans were concerned that adoption of 1125/60 as a world production standard would damage their chances of participating in HDTV equipment markets. The largest European consumer electronics producers—especially Philips, Bosch, and Thomson—therefore supported a European response to the Japanese HDTV initiative. There were two main thrusts: (a) negotiation of an agreement within Europe to do away with the multiple standards within Europe and (b) new funds for collaborative R&D in high−definition technologies.

The Eureka EU95 program was launched in June 1986, at the initiative of French President François Mitterrand, in response to Japanese proposals for the adoption of 1125/60 as a world production standard for HDTV in May 1986. EU95 was one of the first research programs announced under the Eureka rubric.34 The heads of state of the members of the European Community decided at their summit conference in Rhodes in December 1988 to make EU95 and HDTV a high−priority issue in Europe. The German Chancellor, Helmut Kohl, and President Mitterrand had their own bilateral agreement to push for a European answer to the Japanese HDTV challenge. In April 1989, the EC Council of Ministers adopted a decision on HDTV, which outlined a comprehensive strategy for the launch of HDTV service in Europe starting in 1992.35 EU95 itself was renewed and expanded in 1990 when its first phase ended. The initial funding for the program was to have been 190 million ECU for the first four years, from a mixture of public and private sources. The actual expenditure for the first phase of the program, ending in December 1989 was 270 million ECU (approximately $350 million). The second phase began in 1990 and was budgeted at 350 million ECU (around $500 million) for three years.

The most important participants from the beginning were Thomson, Philips, and BTS (a joint venture for advanced television technology created by Bosch and Philips in 1986). Peter Bögels of Philips has been the head of the EU95 Directorate in Brighton, the United Kingdom, since 1986. Thomson directs the program's activities in France. BTS directs the program's activities in Germany. Nokia, a Finnish firm, was added to the inner circle of program directors in October 1989. In May 1990, Philips and Thomson announced that they were planning to spend 20 billion francs (around $4 billion) on the development of HDTV products over a five−year period, but this was to be a Franco−Dutch effort and not strictly part of the Eureka initiative.36

The purpose of EU95 was to develop technologies and prototype equipment for the processing of high−definition video images and stereo sound. From the very beginning, EU95 focused on the development of a high−definition version of a DBS transmission system called MAC (multiplexed analog components), which came to be called HD−MAC. HD−MAC video images have 1,250 lines per frame (double the 625 lines of PAL and SECAM, the current standards in Europe), an aspect or width−to−height ratio of 16 to 9 (the aspect ratio of PAL and SECAM is 4 to 3), and scanning is progressive or noninterlaced (the current standards are interlaced) at 50 frames per second.37 Nevertheless, HD−MAC signals are backward compatible with MAC receivers, so people who purchased MAC sets will still be able to view images produced for HD−MAC receivers.

MAC was developed originally by the Independent Broadcast Authority (IBA) in the United Kingdom. MAC signals are suited to satellite delivery because they are analog and fit nicely within the bandwidth limits of existing satellite transponders. The multiplexing aspect of MAC signals improves the ability of MAC receivers to compensate for errors introduced in transmission. One cannot receive MAC signals on existing PAL and SECAM sets, however, and direct reception in homes is impossible without using higher−power satellites at the transmission end and a satellite dish and decoder at the reception end. MAC was designed to be consistent with an international standard, CCIR 601, negotiated in 1982 at the CCIR plenary. One version of MAC, C−MAC/Packet, was adopted as a European standard by the European Broadcasting Union (EBU) in 1982. The U.K. supported C−MAC because it added data channels that would permit the British Post Office to add a teletext service to the existing television broadcasting services. The French and the Germans opposed C−MAC because of the high cost of C−MAC receivers. They opted for another form of MAC—DMAC—because unlike C−MAC, it was suitable for delivery by cable and did not require special integrated circuits in the receivers.

The French and the Germans developed yet another type of MAC—D2−MAC—which, like D−MAC, could be delivered either by cable or by satellite, but which could be easily upgraded to higher levels of picture resolution. D2−MAC/ Packet was adopted as an EBU standard in April 1985. Distinctive variants of the MAC standard (B−MAC, C−MAC, D−MAC, and D2−MAC) were adopted for use by public broadcasters in the United Kingdom, France, Germany, and the Netherlands, but few MAC receivers were sold initially and there were problems with the launching of DBS satellites. Nevertheless, unlike PAL and SECAM, MAC was designed in such a way as to make it relatively easy to upgrade signals to higher resolutions without losing backward compatibility. This made it possible for Europeans to envision a gradual evolution from PAL and SECAM, to MAC, to enhanced MAC (with wide−screen capability and better sound), and finally to HD−MAC.38

The EU95 consortium was successful in developing prototype HD−MAC cameras, video recorders, and transmission equipment only two years after its formation. It successfully demonstrated HD−MAC equipment first at the International Broadcasting Conference (IBC) in Brighton, the United Kingdom, in October 1988, then at the *Funkausstellung* in Berlin in August 1989, and then again at the National Association of Broadcasters meeting in Las Vegas in May 1991.

The technical success of the EU95 Consortium should be juxtaposed with the so far limited success of MAC itself in penetrating European television markets. MAC has been challenged by a group of private broadcasters who have committed themselves to prolonging the life of the PAL standard by moving to enhanced versions of PAL—PALplus and widePAL.39 Rupert Murdoch's Sky Television, for example, was able to win important increases in European audience shares by directly delivering PAL signals to homes and cable operators via privately−owned medium−power communications satellites, as opposed to the high−power communications satellites owned and operated by the public telecommunications agencies of Europe. All the publicly−owned satellites had been committed to broadcasting MAC signals. Besides the problems connected with launching the high−power satellites, manufacturers had problems producing enough M−AC receivers because of shortages of key components.

Not only did Murdoch steal a march on the public telecommunications operating companies (PTTs) and the public broadcasters by broadcasting in PAL, he also provided more international programming, mainly from the United Kingdom and the United States, to Europeans than the public broadcasters had been willing to provide. Thus, many Europeans bought satellite dishes or subscribed to cable services offering the Sky channels in order to get access to greater variety in programming.40

When Sky Television merged with British Satellite Broadcasting (BSB) at the end of 1990, the new company, British Sky Broadcasting, announced that it would continue to broadcast in PAL and would drop BSB's former plans to convert its signals to MAC. Since that time, Murdoch, together with his European allies, has argued against efforts of the European Community to require all high−powered satellite broadcasters to adopt the MAC standard. The counterargument of MAC supporters has always been that PAL is incapable of being upgraded to high definition, and that failure to enforce uniformity of broadcast standards will confuse consumers and disrupt the future market for HD−MAC products. In essence, the argument is about whether the already rather large investments in developing HD−MAC technologies should be written off. Predictably, those who have made the investments say no.41

Because the Europeans are now firmly committed to HD−MAC and the Japanese are committed to Hi−Vision, the only remaining question in the area of standards is whether the United States will adopt either of these standards or whether it will go its own way. The answer to this question will be given at the end of a standard−setting process still going on under the aegis of the Federal Com−

munications Commission (FCC). If the FCC process arrives at an agreed HDTV standard for the United States, it will do so sometime in 1993. The United States will very likely adopt a third standard incompatible with both the Japanese and European standards, based on a digital version of HDTV technology. It will do so not just because the United States is worried about competitiveness in electronics, but also because neither the Japanese nor the European approach is compatible with the U.S. broadcasting environment (the large number and political power of local broadcasters and cable operators is a key factor here). All the world's equipment makers and program producers, including those in the developing world, will have to adapt their strategies accordingly.

U.S. Reentry into Consumer Electronics Markets

Should U.S. firms reenter markets for the next generation of consumer products? The case for reentry lies largely with the potential benefits of participation in high−volume electronics markets for next−generation products like high−definition television (HDTV). As already argued, there were substantial costs connected with the exit of U.S. electronics firms from consumer markets. The benefits of participating in consumer markets in the 1950s and 1960s were substantial in terms of economic growth, employment, and technological advancement. These benefits shifted to Japan and the Asian NIEs in the 1970s and 1980s.

There is a growing recognition in the United States of the need to reenter high−volume consumer markets. Is HDTV the right vehicle for reentry into consumer markets? Since HDTV requires important advances in integrated circuit and display technologies and because HDTV signal delivery could help to justify the building of a national broadband fiber network, politically important actors in the United States have tended to say "yes."42

U.S. reentry via HDTV in the context of Japanese domination of global markets is not likely to be easy for the following reasons: (a) the U.S. market is open, whereas the markets of Europe and Asia are not; (b) there is only one major U.S. firm in high−volume consumer markets; (c) U.S. consumer circuitry production is weak; and (d) U.S. electronics firms are less vertically integrated than those of Europe and Asia. Only the first two points are elaborated on below.

Prices, and therefore profit margins, in the United States have been notoriously low in consumer electronics for all major producers since the 1970s. There is clearly more competition in U.S. markets than in Europe and Japan. This is one of the main reasons why U.S. electronics firms left consumer electronics—to concentrate their efforts on computers, telecommunications equipment, and automotive electronics. As a result, reentry into consumer markets will be difficult. U.S. firms are likely to demand certain guarantees about enforcing antidumping laws and government support for market−opening initiatives abroad—given their experiences with poor trade law enforcement in the 1970s and 1980s—before they invest their capital in new consumer activities. Major uncertainties connected with new technologies and technological standards will also discourage investment in this area. Thus, the focus of both business strategy and public policy has to be in reducing risk and uncertainty for high−volume production of advanced consumer products in the United States.

The three biggest high−volume consumer electronics producers in the United States are Thomson, Zenith, and Philips. These three firms control about 50 percent of the U.S. market for televisions. Thomson is French, Philips is Dutch, Zenith is from the United States. Zenith has been losing money in consumer electronics markets for a number of years. Thomson has many advantages in its competition with Japanese firms: (a) a relatively sheltered home market in Europe, (b) the considerable technological resources of its acquisitions in the United States (the old RCA and GE consumer divisions), and (c) its status as a highly diversified, global corporation with the backing of the French government. The main strength of Philips is in its excellent record of innovation in both products and processes. Like Thomson, it has a sheltered home market in Europe and has been intelligent in its overseas acquisitions and international joint ventures. But both Philips and Thomson have been losing money in the last few years and have suffered from heavier competition from Asian firms even in their home markets.

Japanese firms are substantially ahead of both U.S. and European firms in developing HDTV products. Besides Japanese dominance of current consumer electronics markets, the Japanese government and electronics firms have been working together to develop HDTV technologies and standards. The Japanese Hi−Vision standard has been in place since 1984. Japanese firms have all developed a broad range of HDTV products, some of which are currently on the market. Neither U.S. nor European firms are as far along in the development or commercialization of HDTV products. Thus, there is some logic in a joint U.S.−European

effort to catch up with Japan. This logic is confounded, to some extent, by the debate over global and regional HDTV standards. As will be discussed below, the United States is very likely to adopt a digital approach to HDTV that will be incompatible with the analog approaches adopted in Japan and Europe.

A Digital HDTV Standard for the United States?

HDTV standards have been set already in Japan and Europe. The Japanese Hi−Vision standard is incompatible with the European standard, HD−MAC. Both rely primarily on direct broadcast satellites (DBSs) for delivery of HDTV signals. Both are analog standards, in that satellite transmission of HDTV signals requires analog rather than digital encoding of video information (in both standards, the audio is digitally encoded). A variety of HDTV standards have been proposed to the Federal Communications Commission (FCC) for the United States. An organization called the Advanced Television Testing Center (ATTC) began testing proposed HDTV systems in the summer of 1991. The ATTC testing process should be completed sometime in 1993. The FCC will base its decisions on HDTV standards on the results of the ATTC testing process. The lateness of standardsetting in the United States is not necessarily a disadvantage, as the United States is likely to select a standard based on digital HDTV technologies.

It was partly as a result of the embarrassing conflict with the Europeans at the Dubrovnik meeting in 1986 that U.S. officials began to question the wisdom of adopting Japanese production standards for HDTV. The very vocal European concerns over the continued viability of their electronics manufacturers in the face of Japanese dominance of HDTV markets made U.S. electronics manufacturers (previously not major participants in U.S. HDTV standards debates) consider the possibility that adoption of Japanese standards would foreclose prospects for their future reentry into high−volume consumer markets.

U.S. terrestrial broadcasters began to realize that adoption of the Japanese production standard might result in acceptance of the Japanese transmission standard (with its 8.1 megahertz channels) which would lead inevitably to a reallocation of television channels by the FCC. The terrestrial broadcasters feared, in addition, that the cable operators might have an advantage in delivering 8.1 megahertz signals during the period in which the FCC was reallocating spectrum. They pushed, accordingly, for a transmission standard that did not disturb the existing allocation based on 6 megahertz television channels. Thus was born the "simulcast' approach adopted by the FCC for the U.S. HDTV standards.43

A number of companies and laboratories proposed HDTV systems for the United States, the most important of which were (a) the ACTV and ADTV systems proposed by a consortium made up of the North American Philips Corporation, Thomson Consumer Electronics, NBC, and the David Sarnoff Research Center in Princeton, New Jersey; (b) the Spectrum Compatible system proposed by Zenith and AT&T; (c) the Narrow MUSE system proposed by NHK; and (d) the all digital system proposed by the American Television Alliance (MIT and General Instruments).44

Philips initially pushed for the adoption of an HD−MAC−like solution to the HDTV standards debate in the United States through its North American subsidiary, but abandoned these efforts as soon as it became evident that they would not be well received. Thomson, in contrast, did not try to impose its European MAC efforts on its U.S. operations, but rather left it up to Thomson USA in collaboration with the Sarnoff Center to come up with a North American answer. Eventually Thomson and Philips teamed up to present a "European" alternative to NHK's "Japanese" solution. The NHK solution was simply to shoehorn the MUSE encoded Hi−Vision signals to fit into the 6 megahertz channels that the FCC insisted on preserving.

As the time came to test the major proposed systems, the FCC, and particularly FCC Chairman Alfred Sikes, expressed a strong preference for all−digital systems. Since both the Japanese Hi−Vision and European HD−MAC standards are analog systems, the U.S. system will necessarily be quite different. It is not clear yet whether the digital approach will work, but Chairman Sikes has leaned strongly in this direction in hopes that an all−digital HDTV will be something the United States can do better than the Japanese and the Europeans. It seems clear, however, that Japanese and European firms will be major suppliers of HDTV systems for the U.S. market, no matter what standard is selected.

There is now solid agreement that it would be desirable for U.S. firms to participate to a greater degree than they have in the last two decades in high−volume consumer electronics markets. There is also increasing consensus that the reentry vehicle for greater participation is HDTV. The U.S. HDTV standard is likely to be distinctive from those in Japan and Europe in stressing digital technologies over analog ones. Whether this turns out to be a boon for U.S. firms remains to be seen. A

precondition for the successful reentry in high−volume consumer markets via HDTV is a set of government policies and business strategies that compensate for the current weaknesses of U.S. firms in consumer components and high−volume manufacturing of systems. Compensation can take many forms, but it has to combine the building of domestic capabilities with the fostering of new international alliances.

Conclusion

Consumer electronics markets have experienced rapid growth and technological change. Those countries—primarily Japan and the Asian NIEs—that understood the importance of consumer electronics as a generator of wealth, jobs, exports, and technology did well for themselves during the last two decades. In the developing world outside Asia, Mexico was the primary beneficiary of North American growth in consumer electronics thanks to the *maquiladora* program. The failure to appreciate the dynamism of the demand for and the technology of consumer electronics badly hurt many European and virtually all the U.S. firms in this industry. The U.S. industry, with the exception of Zenith, had to abandon the field. The European industry consolidated into four major firms: Philips, Thomson, Nokia, and ITT.45 While Europe is in a much stronger position than the United States in consumer electronics, it remains vulnerable to competition from Japan in high−end products and from lower−wage countries in low−end products.

Consumer electronics markets will become more interesting as the transition is made from the current generation of audio and video products to the next. Because of the large costs connected with developing the underlying technologies for HDTV, developing countries are likely to be excluded from all but the lowest value added activities in these new markets. There may be some exceptions among the NIEs (in Korea, for example).

There will continue to be rapid growth in demand for the current generation of products in the developing world and in Eastern and Central Europe. Developing countries may play an important role in developing new forms of personal electronics suited to their own environment. Finally, it will always be wise to search for small market niches which the firms of the developed countries are unwilling or unable to exploit. Enterprises in the developing countries may find some consolation in the likelihood that they will not be alone in having to search for the unappreciated niche markets for opportunities. Most U.S. firms will be in the same boat.

Notes

1. *Consumer Europe 1988* (London: Euromonitor, 1988), pp. 394−49.

2. *Electronic Market Data Book* (Washington, D.C.: Electronic Industries Association, 1988), p. 124.

3. Allen Lenz, "Slimming the U.S. Trade and Current Account Deficits," *The AMEX Bank Review, Special Papers* , No. 16 (October 1988).

4. This figure is based on statistics from the Japanese Ministry of Finance as reported in the *Facts and Figures '91* (Tokyo: Electronic Industries Association of Japan, 1991), pp. 36−37 and 40−41.

5. These figures are according to the Electronic Industries Association of Japan (EIAJ). It should be noted that the EIAJ uses a narrower definition of what constitutes consumer electronics equipment than does the EIA: radios, monochrome televisions, color televisions, video tape recorders, prerecorded disks and tapes, and audio equipment. It does not include home computers or video games, which makes its figures smaller than those of the Using a different classification, Dataquest estimated that in 1986 consumer electronics accounted for about 17 percent of electronics equipment production in North America, Western Europe, and Japan.

6. James H. Wooster, *Industrial Policy and International Competitiveness: A Case Study of U.S.−Japanese Competition in the Television Industry* , Ph.D. dissertation, University of Massachusetts, February 1986, p. 35; Ira C. Magaziner and Robert B. Reich, *Minding America's Business: The Decline and Rise of the American Economy* (New York: Vintage, 1982), p. 171.

7. David H. Staelin, "The Decline of U.S. Consumer Electronics Manufacturing: History, Hypotheses and Remedies," Consumer Electronics Working Group, Commission on Industrial Productivity, MIT, Cambridge, Mass., April 1988, p. 18.

8. Mexican National Chamber of Industry and American Chamber of Commerce in Mexico as cited in the *San Francisco Chronicle* , February 29, 1988, p. A6.

9. Larry Rohter, "Plants in Mexico Help Japan to Sell to U.S.," *New York Times* , May 26, 1987, p. 25; John Eckhouse, "Japan Finds Mexico a Profitable 'Back Door' to U.S.," *San Francisco Chronicle* , March 1, 1988, p. A8.

10. All of the chassis for Thomson's televisions are assembled in its plant in Juarez, Mexico. Only cabinets and tubes are manufactured in the United States.

11. The five largest Japanese color television producers in 1982 were Matsushita, Sony, Toshiba, Hitachi, and Sanyo. See BIS−Mackintosh data cited in Jacques Pelkmans and Rita Beuter, "Standardization and Competitiveness: Private and Public Strategies in the EC Colour TV Industry," paper prepared for an INSEAD Symposium, Product Standardization as a Tool of Competitive Strategy, June 9−10, 1986, p. 26.

12. See David Yoffie, *Zenith and the Color Television Fight* , Harvard Business School, Case No. 9−383−070, May 1984 revision.

13. James E. Millstein, 'Decline in an Expanding Industry: Japanese Competition in Color Television," in John Zysman and Laura Tyson (eds.), *American Industry in International Competition* (Ithaca, N.Y.: Cornell University Press, 1983), pp. 117−18.

14. Wooster, pp. 162−63. This gradual and incremental improvement of insertion equipment provides an interesting parallel with the incremental improvement of semiconductor manufacturing equipment by Japanese firms later in the 1970s. See Jay S. Stowsky, "Weak Links, Strong Bonds: U.S.−Japanese Competition in Semiconductor Production Equipment," in Chalmers Johnson, Laura D'Andrea Tyson, and John Zysman (eds.), *Politics and Productivity: The Real Story of Why Japan Works* (Cambridge, Mass.: Ballinger, 1989).

15. Wooster, pp. 140 and 161. Wooster breaks this down as follows: of the total drop in assembly labor time between 1974 and 1978, 55 percent was accounted for by reduction in component counts, 33 percent by automation of assembly, and 14 percent by reduction in the number of circuit boards.

16. Wooster, p. 146.

17. Staelin, p. 17.

18. The rest of this section relies heavily on .two sources: Richard S. Rosenbloom and Karen J. Freese, "Ampex Corporation and Video Innovation," *Research on Technological Innovation, Management and Policy* , 2 (1985); James Lardner, *Fast Forward: Hollywood, the Japanese and the VCR Wars* (New York: Norton, 1987).

19. U.S. equipment and tape producers thought that half−inch tape would never be able to match the high−quality standards they expected and they did not attempt to create a standard format. The Japanese firms, in contrast, knew that they needed a narrower tape if they were going to be able to market a video recorder for home use and figured that they did not need to build such equipment to studio− or industrial−level standards. On the battle within Japan between Beta and VHS advocates, see Gregory W. Noble, "The Japanese Industrial Policy Debate," in Stephan Haggard and Chung−in Moon (eds.), *Pacific Dynamics: The International Politics of Industrial Change* (Boulder, Colo.: Westview Press, 1989), pp. 73−77.

20. Presentation by Richard Elkus at a meeting on HDTV at the American Electronics Association, Santa Clara, California, June 6,1988.

21. Presentation by Richard Elkus at a conference on "Seizing Opportunities of Change—Strategic Electronic Markets for Semiconductors," sponsored by Dataquest and the Semiconductor Industry Association, Santa Clara, California, September 29, 1988.

22. See Adam Watson−Brown, 'Towards the Triumph of the Matt Black Box," *Intermedia* , 16 (January 1988), p. 24.

23. Data provided to the author by the Semiconductor Industry Association.

24. See Jeffrey A. Hart, "The Origins of the U.S.−Japan Semiconductor Dispute," in Stephan Haggard and Chung−in Moon (eds.), *Pacific Dynamics* (Boulder, Colo.: Westview, 1989).

25. This argument is made most convincingly in Michael Borrus, *Competing for Control* (Cambridge, Mass.: Ballinger, 1988).

26. U.S. International Trade Commissioin, *Liquid Crystal Display Television Receivers from Japan* , USITC Publication 2042, Washington, D.C., December 1987; Michael Borrus and Jeffrey A. Hart, "Display's the Thing: The Real Stakes in the Conflict over High−Resolution Displays," Working Paper 52, Berkeley Roundtable on the International Economy, March 1992.

27. Borrus and Hart.

28. *Facts and Figures on the Japanese Electronics Industry* (Tokyo: Electronic Industries Association of Japan, 1988), p. 51.

29. See, for example, Alan Cawson, Peter Holmes, and Anne Stevens, "The Interaction Between Firms and the State in France: The Telecommunications and Consumer Electronics Sectors," in Stephen Wilks and Maurice Wright (eds.), *Comparative Government−Industry Relations* (Oxford: Clarendon Press, 1987); Rhonda J. Crane, The *Politics of International Standards: France and the Color TV War* (Norwood, N.J.: Ablex, 1979).

30. Interview with a representative of the Electronic Industries Association of Japan in Düsseldorf, Germany, June 1987.

31. *Japan Electronics Almanac 1989* (Tokyo: Dempa, 1989), Chapter 9.

32. "N.V. Philips Enters China Color TV Tube Venture," *Electronic News* , November 23,1987, p. 7.

33. NTSC images have only 525 lines, while PAL and SECAM images have 625. Scanning rates for NTSC images are 60 per second, while those for PAL and SECAM are 50 per second.

34. Eureka began in July 1985 with the membership of 19 European nations as a way of pooling research efforts across Europe. Eureka was seen as a less bureaucratic alternative to the mechanisms established by the European Commission to conduct joint European research in high technology. It was also, to some degree, a response to inducements from the Reagan Administration to involve Europeans in research for the Strategic Defense Initiative.

35. This decision is labeled 89/337/EEC in European Community documentation. It states five objectives: (a) making sure that European industry develops all the technology needed for HDTV services, (b) promoting the adoption of 1250/50 as a global standard, (c) promoting the widespread use of 1250/50 globally, (d) promoting the introduction of HDTV services in Europe as soon as possible after 1992, and (e) making every effort to ensure that the European film and production industry occupy a competitive position in the HDTV world market. For commentary, see Adam Watson−Brown, "Hype, Hope & Clarity," *Television: Journal of the Royal Television Society* , November/December 1989, pp. 312−15.

36. Philips plans to invest 11 billion francs, Thomson 9 billion. See Office of Technology Assessment, *The Big Picture, HDTV and High−Resolution Systems* (Washington, D.C.: U.S. Government Printing Office, June 1990), pp. 32−34; Patrick Samuel, "High−Definition Television: A Major Stake for Europe," in John F. Rice (ed.), *HDTV: The Politics, Policies, and Economics of Tomorrow's Television* (New York: Union Square Press, 1990); and William Sweet, "Future of Electronics Companies at Stake in De−

velopment of New TV Systems," *Physics Today* , 44 (March 1991), pp. 57−61.

37. "HD−MAC" is frequently used synonymously with "1250/50" in discussion of the European HDTV standard because HD−MAC, which is a transmission and reception standard, requires a studio or production format of 1,250 lines per frame and 50 frames per second. To be more accurate, however, one should note that the 1,250/50 production format may produce digital signals that have not been encoded by HD−MAC encoding methods. The reader should keep this distinction in mind, especially in the section on the case of HDTV Fine Arts Production.

38. See Ronald K. Jurgen, "Chasing Japan in the HDTV Race," *IEEE Spectrum* , October 1991, p. 28; Adam Watson−Brown, "The Campaign for High Definition Television: A Case Study in Triad Power," *Euro−Asia Business Review* , 6 (April 1987), pp. 3−11; Adam Watson−Brown, "Towards the Triumph of the Matt Black Box," *Intermedia* , 16 (January 1988), pp. 21−24; and "How Soon the Super Telly," *Economist* (January 30,1988), p. 70.

39. PALplus is an improved definition version of PAL, which makes the image clearer by correcting errors introduced in transmission of PAL signals. WidePAL is an enhanced definition version of PAL, which makes the image wider by moving from the current 4−to−3 aspect ratio to the 16−to−9 aspect ratio of HDTV, but without great increases in picture resolution.

40. I am indebted to Adam Watson−Brown and Hans Kleinsteuber for explaining these details to me. See also Alan Cawson, "The Politics of Consumer Electronics: The British and European Industry in the 1970s and 1980s," rough draft of a unit produced for the Open University Social Sciences course Running the Country, University of Sussex, September 1990.

41. Interview materials; Jeffrey Hart and John Thomas, "Corporatism for Competitiveness? Tracing Policy Networks in the New European Community," unpublished manuscript, Indiana University, Bloomington, February 1992.

42. For elaboration of these points, see Jeffrey A. Hart, *Strategic Impacts of High Definition Television for U.S. Manufacturing* (Ann Arbor, Mich.: National Center for Manufacturing Sciences, September 1989), p. 42.

43. The simulcast approach means that all broadcasters would be allocated two 6−megahertz channels, one to continue broadcasting NTSC signals and the other for HDTV. People with NTSC receivers do not have to scrap their sets or buy downconverters, while people buying new televisions have an incentive to buy an HDTV set.

44. See William Sweet, "Future of Electronics Companies at Stake in Development of New TV Systems," *Physics Today* , 44 (March 1991), p. 57.

45. Although ITT is nominally a U.S.−owned corporation headquartered in the Bahamas, its operations and personnel are heavily oriented toward Europe.

6—
Telecommunications Equipment Markets into the 1990s

William W. Ambrose

The 1980s was a decade of transition in the telecommunications industry. It was a period of deregulation, privatization, and consolidation. Driven by rapid technological innovation and demand growth, many of these strategic shifts are being played out in the 1990s.

The key to understanding the telecommunications equipment industry, and where it is headed, is the relationship between buyer and seller. This relationship is changing dramatically because of rapid developments in electronics technology and the liberalization of distribution and ownership. The telecommunications industry is over a century old. For most of its existence, the industry's primary role has been to provide the capability for two−way voice conversations. Telephone service has been provided either by government−owned monopoly carriers or by heavily regulated public utility companies. Telephone equipment manufacturers evolved to serve public utility telephone companies or post, telephone, and telegraph (PTT) ministries. Telephone companies and PTTs dictated to their manufacturers what specifications to follow. In Europe and North America, dozens of telephone equipment suppliers emerged to serve their local PTTs and telephone companies. Networks outside Europe and North America were built largely by PTTs of the colonial powers, or by multinationals such as ITT, Cable and Wireless, and France Cable et Radio. Suppliers to these networks were the same ones that served their home PTTs.

A high degree of vertical integration characterized the industry. PTTs and regulators felt that close cooperation between the operating company and the equipment supplier was essential to ensure reliable service and to coordinate the massive engineering undertaking of wiring a nation. Equipment suppliers typically were owned by the telephone company, such as AT&T with its manufacturing subsidiary Western Electric Co. and Bell Canada with its Northern Telecom Ltd. manufacturing subsidiary, or they received substantial government subsidies for research and development (R&D) and engineering, such as Siemens in Germany, Alcatel and Thomson in France, Philips in the Netherlands, Ericsson in Sweden, GEC and Plessey in the United Kingdom, various ITT subsidiaries throughout Europe, and NEC, Fujitsu, Oki Electric, and Hitachi in Japan. All these suppliers enjoyed fiercely protected market positions in their home countries. Vertical integration was the mold within the captive manufacturing sector as well. Equipment manufacturers typically produced the majority of pieces and parts making up the assembly process, from rubber grommets to iron housings. Telecommunications operating companies could dictate the specifications because they were the ones in control of technology. The operating companies were the innovators and the costs of R&D could easily be absorbed by rate and tax payers.

But that is all changing. The control of technology is shifting, and indeed has shifted, from operating companies to the suppliers. Increasingly, the operating companies are becoming dependent on their suppliers not only for new developments and applications, but increasingly for basic operation and maintenance of new designs. Liberalization of telecommunications markets, moreover, has shifted buying power from the hands of operating companies into the hands of end users. Users are demanding lower costs, greater capabilities to handle data, video, and voice, and the ability to manage their own networks.

The pressures of fast−paced technology and demands for liberalization have exploded the vertically integrated regulated monopoly mold of the past. The market for telecommunications equipment has become more demand−driven, rapidly advancing beyond basic service needs. At the same time, telecommunications equipment suppliers no longer enjoy protected market status with protected margins. The global telecommunications market has been splintered. Market niches proliferate as new technologies and innovations render existing products and distribution patterns obsolete. The multiplying opportunities are attracting new entrants in droves.

The electronics revolution is also contributing to a globalization of telecommunications markets. To be able to afford the escalating R&D costs required to stay in the technology race, manufacturers are forced to expand market share outside their home markets. At the same time, the additional capabilities that come with technological developments make it easier for suppliers to cross entry barriers. As a result, established suppliers are stepping up activities in export markets. Increasing competition and escalating R&D expenditures have forced many of the largest telecommunications suppliers to merge or forge strategic alliances with competitors.

Industry consolidation, rapid technological progress, and shifts in distribution will continue throughout the 1990s. These forces will have a major impact on telecommunications equipment markets. The unregulated sector will form a larger share of the total market. The changes in the industry will facilitate faster growth of telecommunications markets in developing countries, and will foster technology transfer and shifts in production to those regions. New technological developments and distribution trends will mean tremendous opportunities for innovation.

Global Technology Trends

Nothing has had a greater impact on the world telecommunications market than the invention of the transistor and subsequent evolution of the microelectronics industry. The electronics revolution is facilitating the rapid introduction of new features and capabilities. It is also one of the driving forces behind liberalization and demonopolization.

Impact of Electronics

The ability of electronic components to handle millions of instructions per second and to store billions of bits of information on a postage stamp−sized chip has dramatically transformed the telecommunications industry. Electronics technology has greatly enhanced the functional capabilities of both network and terminal equipment. The introduction of complementary metal oxide semiconductors (CMOSs), high electronic mobility translators (HEMTs), and gallium arsenide large−scale integrated circuit (GaAs LSI) to semiconductor technologies have greatly increased processing speed and quality at the same time that it has reduced component costs. The steadily improving cost−performance curve has extended the application of digital technology to analog−digital conversion, signal processing, band compression, video processing, statistical multiplexing, and a wide range of functions.

The impact of electronics on the telecommunications system can be summarized as follows:

Cost: greater integration of electronic components allows telecommunications equipment to ride the slope of the electronics cost−performance curve;

Size: digital electronic switching exchanges that are the size of a modem refrigerator can now handle what once required a whole room full of older electromechanical equipment;

Capacity: information can be transferred more rapidly, and digital multiplex and compression technologies made possible by electronics can vastly increase the volume of information transmitted; and

Operation and maintenance: software control of remote, computer−controlled equipment can easily be integrated within the communications network itself.

One of the more important new directions in component technology, which is already beginning to have an effect on telecommunications technology, is that of opto−electronics. Fiber optics technology employs opto−electronic components, such as laser diodes, but most of the componentry is electrical. In the future, opto−electronic components will follow the path of integration taken by electrical semiconductors. Opto−electronics will increasingly be integrated into switching, transmission, and eventually processing applications. Right now, the cost of producing integrated opto−electronic components is prohibitive. But with component costs continuing to decline, it is only a matter of time before an optical revolution overtakes the telecommunications industry.

Transition to Digital and Optical Fiber Technology

The clear advantages of digital technology have resulted in its broad application in the telecommu−

nications market. The advantages were initially more obvious for high−capacity transmission links characteristic of trunk networks. Consequently, trunk exchanges and long−haul transmission links have been the first to be digitalized. AT&T began implementing digital trunk switching in 1964 with its no. 4ESS digital exchange; its local digital exchange, no. 5ESS, was not fully implemented until the early 1980s.

Most telephone administrations have by now made a complete transition to digital technology in all stages of switching—local, trunk, transit, and international—and every level of the inter−exchange transmission hierarchy. However, countries vary widely in the amount of progress they have made toward digitalization. Germany's local switching network is currently only about 3 percent digital, while the French local network is 70 percent digital.[1] Some countries, such as Brazil and the Netherlands, have moved more quickly to digitalize local networks prior to digitalizing the trunk network. The most common network strategy is to implement digital technology first on the trunk network and on the links between local exchanges, otherwise known as junction links. The last step of the digitalization process will come in the "last mile" of the network, or the connection between subscriber and switching center. This local loop is almost universally analog. While customers are building largely digital local networks on premise, digital−to−analog and analog−to−digital conversions are required to connect to the local central office. Customers with large private networks are installing digital links to overcome this obstacle, but single−line and small business users continue to face this barrier to digital services.

The introduction of optical fiber technology has followed closely the pattern of digitalization around the world. The cost and capacity advantages have been most obvious in long−haul applications, and again in junction links. With the implementation of 565 Megabits per second and 1.7 Gigabits per second optical transmission systems, operating companies can replace dozens of coaxial cable links with a single strand of optical fiber. And while coaxial systems required repeaters every 1.5 km, fiber optic systems generally require repeaters only every 30−50 km. High−performance fiber optic systems have been implemented that carry signals 200 km without repeaters.

As with digital, the local loop is the final frontier for fiber. U.S. Bell operating companies are now providing fiber optic loops to high−capacity users, as are telephone companies in Japan, Hong Kong, France, the United Kingdom, and elsewhere. Hopes in the industry are pinned on anticipated demand for full−motion video services. Fiber optic capacity will be required in the loop to provide such services.

Changing Cost Structure

With the revolution of electronics technology and the evolution of systems and software design to make use of these new capabilities, the cost structure has changed dramatically in the telecommunications equipment industry. In the past, the costs of switching and transmission products were almost entirely hardware−based and easily determined. The labor costs associated with engineering the exchange for the network were also an important component, but much of the cost of custom engineering was absorbed directly by the operating company. The end products of the production process—relays, frames, switches, and cables— were little different from the components of an automobile.

That is not the case today. Telephone exchanges and private branch exchanges (PBXs) are now capable of doing more than simply switching telephone calls. Exchanges can now keep track of a call's duration, bill the subscriber, diagnose faults throughout the system, reroute calls to another predesignated destination, identify callers, and switch data, voice, and video signals. These capabilities are implemented by the electronics hardware, but they are accessed and managed by software.

Telecommunications equipment development costs are becoming dominated by software development costs. Most switching suppliers, for example, now estimate that software development accounts for 60 percent or more of total switching development costs. The complexity of the software increases rapidly with the size of the exchange. Even taking into account the R&D costs associated with the integrated circuits purchased off−the−shelf, software development is close to half of total switching R&D.

Development costs must now be borne largely by suppliers. The engineering costs associated with electromechanical systems in the past were largely variable and clearly identifiable. Specific hardware components had to be designed to meet the operating companies' special requirements. By contrast, the cost of developing software−driven systems is now largely fixed. Instead of engineering a different system for each customer, suppliers spend most of their R&D budgets on developing the core system, including the extensive software library re−

quired to run it. Moreover, the overall cost of developing such increasingly complex systems is skyrocketing. ITT spent some $1.5 billion on the development of its System 12 digital switching system, and AT&T spent nearly $1 billion to develop its no. 5ESS switching systems.

Distribution Trends

Largely in response to changing cost structures brought about by electronics, along with the evolving capabilities of electronics technologies, the global telecommunications market is experiencing major shifts in distribution patterns. First and foremost among these changes is the shift in the provision of service, which is rapidly being liberalized around the globe.

Liberalization of Services

Starting with the AT&T break−up, and the events leading up to it, a wave of deregulation has swept the globe. Shortly after the Bell System was split up, both Japan and the United Kingdom initiated privatizations of their respective government−owned monopoly carriers (NTT and British Telecom) and introduced competition at various levels of services and networks. Other governments have followed suit, including those of Argentina, Chile, Mexico, Malaysia, and Venezuela, and reforms are at various stages of progress in Australia, Brazil, the Republic of Korea, Pakistan, Singapore, Sri Lanka, Taiwan (China), Thailand, Turkey, Uruguay, and other regions or economies.

While debates continue in many countries about the prudence and economics of privatizing state operating companies, liberalization has proceeded rapidly in certain segments of the telecommunications sector. Areas that have been opened to competitive supply over the last decade in most parts of the world include (a) the provision and maintenance of customer premise equipment (CPE), such as PBX and key telephone systems, and telephone sets, modems, and the like; (b) the provision of paging and mobile telephone services; (c) the construction and operation of private data communications networks; and (d) the provision of value−added services (VASs), such as electronic data bases, electronic mail, and video conferencing.

CPE supply and distribution is probably the most widely liberalized worldwide. Once the exclusive province of the monopoly telephone utility, almost every country now allows users to purchase or lease PBX and business telephone equipment directly from the manufacturer or its distributor. The provision of single−line sets is still regulated in many countries, but purchased sets are interconnected freely in most countries whether allowed or not. Liberalization of data communications and mobile services has progressed more slowly, but the trend is irreversible. Mobile telephone and radio services continue to be regulated on a regional basis within countries, as with any user of radio frequency services, but ownership of operating franchises is being liberalized in a growing number of countries. VAS providers generally must operate through the public network, but moves to relax such controls are gaining momentum.

One implication of liberalization for the telecommunications equipment manufacturing industry is a proliferation of customers. Instead of supplying a single operating company, manufacturers must target a growing number of customers among cellular operators, end users, data communications providers, and, in many instances, competing voice networks.

Vertical Disintegration and Liberalization of Manufacturing

While reform of the traditional monopoly carriers is picking up speed worldwide, liberalization of the equipment supply side is more advanced. Increasingly, governments are determining that competition helps local industries to keep up with the dynamics of telecommunications and electronics. National markets, generally speaking, are no longer large enough to support captive suppliers, which need greater sales volumes to support massive investments in R&D and capital. Without the sales volumes to stay competitive on a global basis, national manufacturing industries will tend to lag both technologically and on the basis of cost. In turn, the operating companies—their customers— will find themselves falling behind other nations in their capabilities and levels of service because of a lower level of available technology, and because of the higher cost of equipment in general. In developing countries, where access to investment capital is a major constraint, inefficient equipment suppliers result in slower growth to meet final user demands.

Now it is true that a protected manufacturing industry could build on its domestic base and develop an export industry that does indeed capitalize on global economies of scale. Such a scenario, however, is rare. Japan's industrial policy has come the closest. Although not a monopoly, Japan's largely protected telecommunications industry— led by four suppliers: NEC, Fujitsu, Hitachi, and Oki—has managed to leverage its close working relationship with NTT, until recently Japan's tele−

phone monopoly, to establish leading positions in world equipment markets. Similarly, France's aggressive strategy to implement nationwide digital switching during the 1970s enabled its captive supplier CIT Alcatel to emerge as a world leader in digital switching technology, with versions of the French switch (the E−10) having been adopted in over 50 countries.

More commonly, however, captive suppliers are hamstrung by the particular requirements and procedures of the dominant operating company. And with no competition, suppliers have little incentive to reduce costs or shorten development schedules. Germany's strict protection of its local suppliers contributed to the Bundespost network having one of the lowest digitalization rates in the world. Similarly, British Telecom's control of the development of the System X digital switching system resulted in huge cost overruns and delays.

Governments are moving to reduce protection of local industry in an effort to reduce costs and promote innovation. In Europe, governments are actively seeking standardization across national boundaries to allow free competition within Euro−Dean borders. Breaking up the captive market relationship between AT&T's Western Electric manufacturing company and its Bell System operating units was one of the driving forces behind the U.S. government's antitrust litigation. In the United States during the 1970s, several of the large, independent telephone companies, including United Telephone and Continental Telephone, were forced to sell off captive supply companies because they could not afford the high stakes of the electronics industry.

These events have led to vertical disintegration within the industry. Telephone company ownership of production facilities is now largely limited to India, Pakistan, Iran, Eastern Europe, and Canada (where Bell Canada Enterprises owns a majority stake in Northern Telecom Ltd.). Nevertheless, changes are taking place in these economies as well. Pakistan has allowed a state−owned manufacturer to establish a joint venture with a foreign supplier. India has allowed state government−owned electronics companies to compete with the federally owned Indian Telephone Industries. Eastern European governments are broadly liberalizing procurement under the new political environment enveloping the region.

The issue of protection remains one of great debates among the developing countries. One argument in favor of protection is the creation of employment. Another is that, given the difficulty of competing globally, local industries need a period of incubation to develop a capacity to compete. As a result, some degree of protection is evident in many markets of the larger developing economies for telecommunications equipment, including Argentina, Brazil, the People's Republic of China (PRC), Egypt, India, Korea, Mexico, Pakistan, Taiwan (China), Turkey, and many more.

While the debate continues, however, many of these economies are in the process of relaxing import restrictions. Brazil has begun to open up international bidding for digital switching, fiber optics, and data communications projects. Argentina, Mexico, Venezuela, and several other Latin American countries have recently reduced protection through reducing import tariffs or eliminating local production requirements. Turkey recently privatized its telecommunications manufacturing industry and reduced import barriers.

The Global Market Segmented

Historically, the telecommunications equipment market was made up almost exclusively of purchases made by monopoly operating companies. Today, spending by the same general category accounts for little more than half the total world market. Expanding their share of the market are private satellite networks, mobile telephony, data communications, PBX and key telephone systems (KTSs), and other CPE equipment including telephone sets and advanced terminals (see Table 6.1). The world market for switching, transmission and cable—the mainstays of the public network market—accounted for 59.5 percent of the total telecommunications market in 1984, and only 54.5 percent of the total market in 1989.[2]

While public network spending—expenditures by telephone companies on switching, transmission, and cable—accounts for the largest share of the telecommunications market, spending by end users on private networks is growing faster. Seeking competitive advantage from earlier introduction of new technology, end users demand more functional customer premise equipment, state−of−the−art concentration and compression technologies, such as T−1 multiplexers, high−speed packet−switching technologies, and more sophisticated network management systems. The driving force behind the growth of the private network market is cost containment. Users want to make use of the latest technology to reduce telephone bills and increase productivity. The lion's share of private network equipment is connected to the public network, including customer premise equipment, multiplexers, and high−speed modems. A growing number of users, however, are taking complete responsibility for their networks by es−

Table 6.1
Worldwide Telecommunications Expenditures by Equipment Type

	USS billions			*1984−94*
Equipment type	*1984*	*1989*	*1994* a	*growth (%)*
Switching	21.0	27.4	34.5	5.1
Transmission	17.4	21.5	27.9	4.8
Cable	6.9	8.9	10.9	4.7
Satellite	2.4	3.4	3.9	5.0
Mobile	4.0	9.4	12.3	11.9
Data communications	5.1	10.5	15.8	12.0
PBXand key telephones	5.8	8.9	10.3	5.9
Customer premises equipment	7.2	9.3	11.1	4.4
All other	6.3	6.7	6.9	0.9
Total	76.1	106.0	133.6	5.8

a . Projection

Source: Arthur D. Little.

tablishing entirely private transmission networks, including microwave and satellite.

Public Switching

Switching equipment serves as the nerve center of the telecommunications network, providing connections between any two lines. Switching systems can range from those serving a few dozen telephone lines to those serving over 100,000 lines. Once performed by human operators manually inserting line terminations into lighted switchboards, the switching function is now handled by state−of−the−art computers that route calls electronically through semiconductor pathways. Switching expenditures typically account for 35−45 percent of the public network market in any given country. Altogether, switching purchases make up nearly 25 percent of the total world market for telecommunications equipment.[3]

Telephone companies are rapidly replacing electromechanical switching exchanges with stored−program−control (SPC) digital switching systems. About 550 million switching lines are installed worldwide; of these, about 150 million are now digital. Another 80 million are SPC analog systems, primarily AT&T 1ESS and 1AESS exchanges in the United States, and ITT's Metaconta outside the United States. The remaining 320 million switching lines are older electromechanical systems, including crossbar, rotary, and Strowger step−by−step, with some pockets of manual systems in service in Asia, Africa, and Eastern Europe. About 45 million new switching lines, including trunk lines, are added per year, of which 20−25 million replace existing analog equipment. Of the total market in 1990, over 90 percent of shipments were digital equipment. By contrast, only 15 percent of the market for switching lines in 1982, which totaled about 28 million lines, was supplied by digital systems. For the most part, analog shipments continue only in developing countries that have established local production of analog systems, including Brazil, China, India, Korea, Poland, and the former U.S.S.R. Analog parts are also being produced to expand analog systems already in service.

Early fears that digital exchanges would be quickly replaced by a new generation of switches have subsided.

Rather, new technologies are being developed to modernize line cards, to boost processing speeds, and to enhance functionality of existing digital exchange designs. New technologies, such as integrated services digital network (ISDN), are being designed for implementation on existing digital networks. Optical technologies will not take over the switching network for many years to come, and they are expected to replace components of the exchange only gradually.

Because of the flexibility of digital technology, suppliers are scrambling to establish an installed base. An installed base of digital exchanges will almost certainly ensure a steady flow of revenues and profits in the decades ahead. Suppliers will seek to maximize their installed base, almost at any cost, until global digitalization is approached at the end of the century. In the past, suppliers have been content to supply their home market with occasional exports. Today, the cost and technology equations are forcing suppliers to expand their installed base as much as possible. The result has been an extremely competitive global market place. In some markets, prices have fallen below costs.

The realities of the switching market, therefore, seem to be a fierce short−term battle for market share among suppliers as each strives to maximize its installed base. This battle has driven down prices for basic configurations—to $150 per line and below—in the more sought−after markets. In less attractive markets, prices have remained in the $300−$700 range, depending on contract size, features, and exchange size. The battle to build a base is a global one, and the stakes are high. Table 6.2 ranks suppliers by digital installed base. Those suppliers in the best position to exploit their installed base are Alcatel, Northern Telecom, AT&T, and Ericsson.

However, actual line installations will become a smaller part of the switching market as a whole. In the 1990s, marketing emphasis is shifting from

Table 6.2
Digital Public Switching Installed Base by Supplier, 1990

Supplier	*Model*	*Installed base (millions of lines installed)*	*Percentage of total*
Northern Telecom	DMS	45	20
Alcatel	E−10, S12	43	19
AT&T	5ESS	35	16
LM Ericsson	AXE	31	14
NEC	NEAX61, D70	19	8
Siemens	EWSD	12	5
Fujitsu	FETEX150, D70	12	5
Other		28	12
Total		225	100

Source: Pyramid Research estimates.

initial digital installations to new features and applications, including ISDN, and the hardware required to implement them. While line installations will grow slowly or level off in many countries, spending will grow steadily to purchase new operational and maintenance capabilities, ISDN line cards, super processors, and eventually packetswitching and fast−packet capabilities. The prices for these new capabilities will be difficult to compare internationally; they are likely to be high.

Transmission

The $20 billion world market for transmission equipment, like the switching market, is being fueled by programs to digitalize existing analog facilities. The transmission market has shifted almost completely from analog cable, microwave, and frequency division multiplex (FDM) multiplexers to digital fiber optic systems, digital microwave, and pulse code modulation (PCM) multiplex equipment. The largely analog installed base will mean a steady replacement market for many years to come. In the past, analog microwave radio systems were the technology of choice for long−distance communications. Copper cable was used extensively in junction networks and shorter distance long−haul connections. The advent of fiber optics and new satellite technologies, such as time−division multiple access (TDMA), have created new competition for traditional microwave and cable suppliers.

The fiber optics market exploded in the early to mid−1980s, driven by purchases by U.S. long−haul carriers that were positioning themselves to compete with a deregulated AT&T. The growth of the market has since shifted to Europe and Asia. Fiberoptic submarine cables are being installed in trans−Atlantic and trans−Pacific routes as well as in smaller regional networks in the Pacific Basin, the Caribbean, the Mediterranean, and elsewhere. The world market for optical fiber cables is estimated at between 2.0 and 2.5 million fiber−kin for a value of over $800 million.4

Satellite systems have generally played a small role in domestic transmission, but that is changing. With the declining cost of earth station equipment and the proliferation of very small aperture terminals (VSATs), satellite technology is increasingly being employed for domestic service by countries with large areas to cover, such as Brazil, China, India, Indonesia, Mexico, and the former U.S.S.R. Markets for satellite links and VSATs are becoming increasingly popular for private network applications. The VSAT market soared in the United States during the 1980s, giving rise to a number of niche suppliers, including M/A Corn, Equatorial, Tridom, and Comstream. A slowdown has occurred in the United States, resulting in some consolidation, with Hughes acquiring M/A Com, Contel acquiring Equatorial, and AT&T acquiring Tridom.

But the VSAT market is growing rapidly outside the United States. Some studies predict growth of 40,000−50,000 VSATs in Europe alone over the next five years.5 Major VSAT programs are also under way in developing countries. Contracts amounting to over 5,000 VSATs have already been placed in Brazil, with 10,000−20,000 more planned over the next five years. Mexico is also planning to add several thousand to its base of about 1,000 VSATs. Indonesia has begun implementing an initial 4,000−VSAT network. China, India, Turkey, and the former U.S.S.R. are also expected to be huge markets for VSATs over the next decade.

While satellite and fiber optics are steadily increasing their share of the overall transmission market, digital microwave suppliers are still best positioned for replacement of analog microwave networks. Japanese suppliers NEC and Fujitsu have taken advantage of steeply dropping costs of electronic components to capture leading shares of the international market for digital radio systems. Manufacturers in Europe, such as Alcatel, Siemens, and Telettra, and manufacturers in the United States, including Harris Farinon, have also kept pace.

The largest segment of the transmission market is that of multiplexers. An enormous installed base of frequency division multiplex equipment is in place in Europe and North America, and throughout the world. As long−haul transmission and switching capacity is digitalized, FDM equipment must be replaced by PCM equipment. It has been

estimated that multiplex equipment accounts for 52 percent of the world transmission market, with microwave radio making up 18 percent, fiber optic equipment 12 percent, coaxial line equipment 3 percent, satellite 5 percent, and mobile technology 10 percent.6

Cable and Outside Plant

Next to the telephone set itself, telephone cable is perhaps the best−known symbol of the telecommunications industry. After all, it is the cable that provides the connection to the home or business telephone. The copper wire and cable business flourished during the post−World War II reconstruction of telephone networks in Europe and Japan, and during the postwar boom in North America. However, the copper cable business is now mature. The introduction of new technology, however, has spurred growth in another cable segment: optical fiber cable.

The maturity of the $9 billion world cable market is due largely to cable systems' being in place in most developed countries. New transmission technologies, such as high−capacity multiplexers, are designed to use the existing cable investment more efficiently. Copper cable plant will last for several decades. The industry's maturity has led to consolidation and mergers through Europe and North America. Nevertheless, cable construction is still very much a growth market in countries with less developed networks. Fiber optics technology has emerged as the cable system of choice for growth markets, as well as for the replacement of undercapacity or obsolete copper plant. Fiber optics technology is also beginning to be applied to local loop applications. Fiber−to−the−home is still many years away, but changes in the regulation of cable television networks could radically advance this application.

Customer Premise Equipment

Cost containment was the primary motivating factor behind the rapid growth of CPE markets in the 1970s and 1980s. Twenty years ago, most PBX, KTS, and telephone equipment were provided by the telephone company on a rental basis. Telephone companies, in general, were slow to pass along to users the benefits of a steeply sloping price−performance curve of electronics technology. Frustrated by expensive rental charges and the limited capabilities of telephone company equipment, users fought for and eventually won the right to purchase and maintain their own on−premise equipment. Not only did PBX and KTS equipment cost less to purchase directly, but new features such as least−cost routing, automatic call distribution, and call accounting enabled users to save on traffic charges and to maintain tighter security of the network.

PBX and KTS markets exploded in the United States and Canada during the 1970s and early 1980s in the wake of CPE liberalization. Users quickly replaced outdated Western Electric equipment with electronic and digital equipment offered by dozens of new competitors, including Rolm Corporation, Northern Telecom Ltd., Mitel Corporation, TE Communications, Rockwell International, and ITT Corporation. Deregulation of CPE proceeded at a slower pace in Europe and other parts of the world, but by the 1980s most CPE markets were liberalized. Competition has facilitated the rapid introduction of digital technology, and has brought an expanded range of features to office communications networks.

The list of features available on digital PBX systems expands almost daily. Newer models offer combined simultaneous voice and data connectivity. Features such as voice mail, electronic messaging, and sophisticated accounting packages are now commonplace in the office. Suppliers are developing ISDN−compatible PBXs to link directly with primary rate interface standards established by CCITT (Comite Consultatif International Telegraphique et Telephonique).

Competition in the industry has also contributed to expanded functionality and lower−cost terminal equipment. Business telephones typically feature liquid crystal displays (LCDs), speakerphones, and speed dialing. ISDN terminals offering advanced signaling features, such as caller identification, and eventually interactive video may be just around the corner.

Data Communications

One of the fastest−growing segments of the world telecommunications market is data communications. The growth rate of nonvoice network terminals is 20 percent per year compared with only 4 percent growth for connected telephones for voice.7 Data communications spending worldwide grew from $5 billion in 1984 to $10 billion in 1989.8 The growth of the data communications market is being driven by several factors. The rapid proliferation of personal computers in the work place is fueling demand for both local area network (LAN) equipment to attach to internal information resources, and wide area network (WAN) equipment to connect with other offices and remote data bases. Businesses also seek to gain control of their

network facilities and, more importantly, their costs. The LAN market has emerged only in the last decade or so. Start−up U.S. companies like Novel, 3Com, and TOPS have pioneered a market that now totals nearly $4 billion annually. Some predict that the LAN market will reach $8 billion by 1993.9 Growth has slowed in the United States, but strong growth will continue in Europe, Japan, and developing countries.

In the liberalized U.S. market, users have also been rapidly installing network equipment, such as T−1 multiplexers and packet−switching equipment, to establish private WANs that connect to remote sites through the public network. Sophisticated multiplexer, compression, and network management features allow users greater traffic capacity at lower costs and greater networking flexibility than standard leased line connections. Demand for high−speed modems, statistical multiplexers, and related hardware at the termination of these networks has also been strong. Data multiplexing in the United States has evolved around the 1.544 Megabits per second T−1 multiplexing standard. In Europe and elsewhere, the CCITT's standard 2.048 Megabits per second, or E−1 standards, are followed. WAN and E−l/T−1 markets are now emerging in Europe and Asia, and are growing rapidly in the most liberalized markets around the world.

Mobile Telephony

One of the more revolutionary developments in telecommunications over the last decade has been the advances in mobile radio technology, especially cellular telephone technology. Other important innovations include paging technology, mobile data technology, and wireless telephone technology. Initially designed to replace the capacity−restricted mobile radio networks for automobiles, cellular has spurred a new industry in itself with no end in sight for growth. Over 10 million subscribers are now connected to cellular networks worldwide, including about 5 million in the United States alone (see Table 6.3). Although most cellular subscribers in developed countries are connected via car phones, cellular also has a potentially large market in developing countries as a substitute for scarce wired telephones in urban areas and as a provider of service to unattended provincial and rural areas.

All cellular systems installed to date are based on analog technology, with a variety of standards being employed. The Advanced Mobile Phone Services (AMPS) standard is the most widely implemented by virtue of its being the standard in the United States. In Europe, the Nordic Mobile Telephone (NMT) standard is the most widely used, although Europe's largest single country network is in the United Kingdom, which has adopted the Total Access Communications System (TACS) standard. France, Germany, and Italy have each adopted their own standards (Germany's has also been adopted by Austria and Switzerland). Future directions for mobile telephony include wireless loop systems for congested urban areas and rural networks, wireless PBXs, and mobile data networks for special services. The pace of growth will be determined, in part, by improvements in battery technology and portable reception.

Table 6.3
Cellular Subscribers in Service by Region, 1989 and 1990

	Millions of subscribers		*Growth (%)*
Region	*1988*	*1990*	
United States and Canada	3.5	5.6	26.5
Europe	2.2	3.1	18.7
Asia and the Pacific	0.8	1.6	41.4
Latin America and the Caribbean	0	0.1	123.6
Africa and the Middle East	0.1	0.1	31.3
Total	6.6	10.5	26.3

Source: Pyramid Research estimates.

Value−Added Services

New technological capabilities are spawning a host of new services, such as electronic mail, videotex, voice mail, audiotex, video conferencing, data base retrieval, and electronic data interchange (EDI) protocol conversion services and electronic funds transfer services (EFTSs). Telephone companies and private value−added networks (VANs) are providing these new services largely through public network connections. However, some users are implementing VASs on internal and private networks. The growth in the VAS market is spurring demand for specialized terminal equipment such as multifunctional terminals, video terminals, and special access equipment. Declining costs of video codecs, memories, and processors will accelerate growth of these markets in the years ahead.

Geographic Trends

Both demand and supply of telecommunications equipment have largely been concentrated in the developed world. Typical telephone penetration

rates in North America and Europe are one telephone line for every one to three people. Among the developing countries of Latin America, in contrast, penetration on average is closer to one telephone for every 10−20 people. In China and India, which together are home to nearly 2 billion people, telephone penetration is less than one telephone line per 100 people. The situation is even worse in Africa and many other Asian countries. Africa, Asia, and Latin America, however, are the growth segments of the market. Increasingly, developing countries are recognizing the importance to their economies of building a modem telecommunications infrastructure. Production of telecommunications equipment has also been concentrated in the developed countries of Europe and North America, and Japan. An industrial base also exists among former Council for Mutual Economic Assistance (COMECON) countries to serve Eastern Europe and the former U.S.S.R. However, this, too, is changing. Hans Baur, executive vice president of Siemens AG, noted in an address to the TELECOM 87 conference in Geneva that since 1950 the number of countries with their own telecommunications industries and completely self−sufficient supply has risen from 16 to 30. At the same time their share of the world market has sunk from 97 percent to 70 percent, and another 22 countries have been added whose local telecommunications industries now provide them with partial self−sufficiency.10

Shifts in Consumption

The world market for telecommunications equipment has been growing at nearly 7 percent per year over the last five years and is forecast to grow by 5 percent per year through 1994.11 The developed countries account for about three−fourths of the world market. Markets will grow more rapidly, however, among the developing countries, including the countries of Eastern Europe and the former U.S.S.R. The growth potential in developing countries is enormous. Excluding Japan, Asia can claim about half the world's population, but only about 10 percent of the world's telephone lines. The investment required for Asia to reach half the telephone penetration of Europe would be an estimated $500 billion. Developing countries accounted for 17.3 percent of world demand in 1984.12 In 1989, their share had risen to 20.1 percent. By 1994, the same group is expected to account for 27.5 percent of the market. Eastern European countries and the former U.S.S.R., meanwhile, are expected to increase from 5 percent of the world telecommunications market in 1989 to 6 percent in 1994. Table 6.4 segments the world market for telecommunications equipment by region.

The demand also varies between developed and developing countries. In developing and former Eastern bloc countries, spending is weighted toward construction of basic infrastructure. Over two−thirds of telecommunications spending in these countries is for public network facilities. By contrast, public network expenditures make up only about 55 percent of the total telecommunications markets of the developed countries. A growing share in these countries is spent on CPE, data communications, and specialized networks.

One reason for this disparity is that the basic networks in Europe, North America, and Japan are largely in place. The lion's share of spending goes to replacement of obsolete equipment. Net growth of the networks in these regions, measured in main telephone lines, is 3−4 percent per year. The corresponding growth in Africa, by comparison, is about 8 percent per year. In Asia, excluding Japan, the growth rate is nearly 9 percent per year (see Table 6.5). Some large markets are growing even faster (for example, China growing more than 20 percent per year in the early 1980s). The countries in Africa, Asia, Eastern Europe, and Latin America typically spend a larger proportion of their telecommunications budgets on basic local loop construction: wiring customers to switching offices. Much of the labor and often the cabling can generally be sourced locally.

Table 6.4
Telecommunications Equipment Expenditures by Region, Selected Years

Region	*US$ billions* *1984*	*1989*	*2994* a	*1984−94 growth (%)*
United States and Canada	30.3	40.2	48.8	4.9
Europe	26.0	36.0	47.5	6.2
Asia	14.0	20.1	25.4	6.1
Latin America and the Caribbean	3.0	4.4	5.1	5.5
Oceania	1.2	2.9	3.8	12.2
Africa	1.6	2.4	3.0	6.5

Total	76.1	106.0	133.6	5.8

a . Projection

Source: Arthur D. Little estimates.

Table 6.5
Telephone Network Growth, 1983−93

	Millions of main telephone lines			*1983−93 growth (%)*
Region	*1983*	*1988*	*1993*	
United States and Canada	123.5	144.7	166.4	3.0
Western Europe	122.3	150.7	185.0	4.2
Eastern Europe and the former Soviet Union	34.5	44.5	55.1	4.8
Japan	43.7	50.7	58.8	3.0
Oceania	7.2	9.0	10.6	3.9
Other Asia	26.4	43.8	62.1	8.9
Latin America	18.1	24.8	38.6	7.9
Africa	4.9	7.5	10.9	8.3
Total	380.6	475.7	587.5	4.4

Source: Pyramid Research estimates.

Shifts in Production

While the developing countries of Africa, Asia, and Latin America have expanded their share of total world spending on telecommunications, so too have they expanded their share of world production. The growth of production in these regions has evolved along two tracks. Along one track, government policies designed to restrict market access and encourage technology transfer have shifted some downstream production and distribution activities to local markets. The economies in which this has been most prevalent in the area of telecommunications include Algeria, Argentina, Brazil, China, Egypt, India, Indonesia, Korea, Mexico, Pakistan, Taiwan (China), Thailand, Turkey, and Venezuela.

In the area of switching, major strides have been made among the developing countries. Korea, and to some extent Brazil and India, are rapidly approaching self−sufficiency in the design and production of some switching equipment. All three countries have successfully developed small digital switching designs. Korea's KTA has installed about 1 million lines of the locally developed TDX−1A and TDX−1B exchanges. During 1990−91, KTA planned to purchase 3 million lines of TDX−1 and another 64,000 lines of its TDX−100, a new 100,000 line switch, giving local designs a 55 percent share of the Korean switching market.

Local suppliers also produce the bulk of transmission equipment being installed in Brazil, India, Korea, and Turkey. A large share of local production in these countries is based on technology licensed from foreign suppliers, but all four countries are developing PCM and fiber optics technology locally. Telephone set production is in place and is rapidly expanding in Algeria, Argentina, Brazil, China, Egypt, India, Korea, Malaysia, Mexico, Pakistan, Singapore, Taiwan (China), Thailand, Turkey, Venezuela, and several other developing economies.

Self−sufficiency is the case among former COMECON countries, but most of the output is largely outdated analog technology. Technological modernization has been sought by former Eastern bloc industries, but East−West trade barriers have prevented technology transfer in the past. Major efforts to update technology and production facilities are now being accelerated as East−West relations continue to thaw.

The second track resulting in a globalization of production is comprised of efforts among developing economies to build up telecommunications export industries. Most notable among economies following this strategy include Korea, Taiwan (China), and other Southeast Asian economies. The telecommunications industries of Brazil, China, India, and Mexico have also had some success. Producers in these countries typically specialize in more commodity−like products, such as telephone sets, modems, key telephones, facsimile machines, and low−end PBX systems. Exports of these products from Korea and Taiwan (China) have gained a considerable market share in the United States, and suppliers, such as Goldstar and Samsung of Korea and Bitronics of Taiwan (China), are developing a presence in Europe and other parts of the world. Developing economies have also been steadily increasing their share of total world telecommunications exports. According to A. D. Little, 19 percent of world exports of telecommunications equipment in 1989 originated from outside of Europe, North America, and Japan. That figure compares with only a 7 percent share in 1984.[13]

Technology Transfer Patterns

The changing economics and globalization of the telecommunications market have contributed to a highly competitive environment, which is pressuring companies to expand internationally. In such an environment, some countries, particularly those with large markets, have learned to leverage their position by requiring technology transfer as part of any purchase contract. Vertically integrated monopoly market structures in Europe resulted in widespread technology transfer during the early

part of this century. Local industries emerged in almost every country of Europe when the economics of telecommunications manufacturing could support the low volumes. Today, countries in Asia, Latin America, and increasingly Eastern Europe, are the ones striving to establish local telecommunications industries. Several economies with large markets in Asia, Latin America, and the Middle East, including Argentina, Brazil, China, India, Israel, the Republic of Korea, Mexico, Taiwan (China), and Turkey have managed to extract concessions from foreign suppliers to transfer technology locally, through licensing, local production, or joint venture. As competition in the world market escalates, suppliers are finding they have to make similar concessions in smaller markets.

Local production of digital switching equipment, for example, is under way, or soon to be under way, in those economies mentioned above, as well as in Indonesia, Malaysia, Thailand, the Philippines, Pakistan, Saudi Arabia, Egypt, Algeria, Tunisia, Syria, Venezuela, and South Africa. Eastern European countries are following suit, with licensed digital switching production planned or under way in Bulgaria, Czechoslovakia, Hungary, Poland, the former U.S.S.R., and Yugoslavia. The strategy of some countries, particularly that of Brazil, India, and Korea, has been to take advantage of initial technology transfer arrangements to develop a local technology capability as well. National projects in all three countries have developed indigenous designs of digital switching, digital multiplex, fiber optics, and digital microwave systems.

Outlook

Your telephone beeps. The name of a business associate appears on the screen. You pick up the handset, and a live image of the caller appears. Or, if you don't want to talk, you press a button, and a prerecorded video will ask the caller to leave a message. The video message will be stored on a cassette or disk for replay at your convenience. Two−way video communications, once only a vision of science fiction enthusiasts, is quickly becoming a reality. The technologies to implement the vision digital switching, fiber optics, and sophisticated terminals are available today. New, lower−cost technologies and shifts in distribution will combine to accelerate the introduction of new services during the next decade.

Video, high−speed data, and new voice services are rapidly coming to the fore in industrialized nations under the banner of ISDN. The technology required to provide such services has been available for years, but advances in electronics and stepped−up competition are driving costs down to the point at which such services are now becoming a commercial reality. At the same time, steady progress in setting standards has been achieved through lengthy deliberations of the International Telecommunication Union (ITU) and its members. And like standard gauges for railway tracks, telecommunications standards will facilitate traffic across borders and across continents.

The concept of ISDN is simple. Rather than implement separate networks for telephone, telex, data communications, and video services, each will be provided over a single network. Merging them is made possible by new technologies enabling each medium to be translated into a standard digital format. The implications of ISDN are enormous. Tremendous cost savings are possible from operating and maintaining a single, standardized network instead of several disparate ones. The advancing technologies, which are paving the way for ISDN, offer a multitude of new service capabilities which promise to alter the way we communicate radically.

The ISDN vision is a single, multimedia network providing voice, telex, video text, facsimile, data communication, one−way and two−way video, and a range of new services not yet invented. Advances in switching technology, fiber optics, and terminals allow the merging of these signals, and offer a tremendous potential to increase the information capacity—voice, data, and video—of the single telephone line. High−capacity fiber optic transmission links and sophisticated switching technologies will greatly enhance the speed and efficiency with which information is transmitted between two points. But from the user's standpoint, ISDN will mean video−telephones, new data and video services, and greater control over information efficiency.

Because of interface standardization, equipment suppliers are able to go about designing sophisticated terminals independently. Rapid advancement of terminal technology is taking place around the world. As a result, costs will drop quickly and a wide range of new multifunction terminals will proliferate. As the network becomes more complex in order to handle the wider variety of information needs and customer options, network management becomes increasingly important. Consequently, suppliers are developing new computerized administrative and network optimization technologies, so that they can control the ever−expanding network.

Sophisticated computer systems are needed to track usage. For telephone companies to generate revenues from new services, usage must be strictly monitored. Sophisticated testing equipment is required to detect faults and ensure that service is maintained—loss of telephone service can often be the difference between life and death. New technologies like digital cross−connects and software−driven miltiplexers can reroute traffic through underutilized facilities. Such technologies will allow telephone administrators to make better use of existing investments. New developments in mobile telephony, meanwhile, promise to revolutionize the local loop. Users have been tethered to the network since the invention of the telephone. New wireless technologies will allow users to roam freely on a global as well as on a local basis.

Vertical Reintegration

The proliferation of new technologies is expected to have a dramatic impact on the telecommunications equipment market. Just as important, however, will be shifts in distribution of services and equipment. In particular, the evolving role of telephone carriers as information providers may very well lead to vertical reintegration within the industry.

Service carriers are just beginning to understand the new roles to which they have been assigned. Technological developments have ushered in a host of new service capabilities. Deregulation is challenging the world's carriers to develop applications and innovative services. While tight control of hardware supply was critical for carriers through most of the twentieth century, control of software development and applications will emerge as the critical competitive factor for carriers into the next century. Carriers will increasingly be competing for value−added and video service revenues. As distributors of these services, each will be striving to differentiate and reduce costs. The technology required to do so is now largely soft−ware−based. Digital switching and transmission equipment will be relegated to the role of service platforms. New services will increasingly be developed within "intelligent networks" or network adjuncts supplied by specialized computer and information system suppliers as well as traditional switching suppliers.

As carriers face new competition from other car−tiers and value−added networks, and eventually from video programming networks, they will find it imperative to develop collaborations with information system suppliers, software developers, data base providers, and entertainment programming companies. Telecommunications equipment manufacturers will be forced to respond to and adapt to these changes.

Geographic Shifts

The leading edge of telecommunications services will be, not surprisingly, among those countries that have ubiquitous digital platforms in place. New value−added services will emerge as important markets in North America, Western Europe, and some Asian countries, such as Japan and Singapore. Elsewhere, the challenge of extending basic service will continue to outweigh the need to develop new services. Developed countries, therefore, are expected to account for most of the demand for new, advanced service capabilities and related hardware and software. Developing countries, however, will continue to increase their share of the market for more conventional telecommunications equipment, such as switching, transmission, data communications, cable, and terminal equipment.

Developing countries are also expected to expand their share of production. Growing software capabilities among the developing countries and the high labor costs of developing software may contribute to a shift in software production to developing countries, where software engineers are paid 10−20 percent of the wages of their counterparts in Europe and/or the United States. Similarly, developing countries are expected to expand their share of telecommunications hardware assembly and component production. How quickly shifts occur geographically will depend to a large extent on the pace of deregulation around the globe. Reform movements in Eastern Europe add a new variable to the scenario. For most countries, liberalization of equipment and service markets is more a question of when rather than if.

Policy Implications for Developing Countries

As liberalization of services proceeds, and as technology evolves at an accelerating pace, the debate continues among developing countries about the level of protection and support to be provided for local telecommunications and manufacturing industries. Among the issues being debated are whether to restrict imports, whether to legislate local procurement, and whether to subsidize local technology development efforts.

In the past, protection has resulted in the emergence of substantial telecommunications production capabilities in several markets of the larger developing countries. In most cases, local producers are either joint ventures between foreign and local parties or local subsidiaries of foreign companies. Stricter protection in India, Indonesia, Iran, Korea, Pakistan, and others resulted in local companies' licensing technology from foreign suppliers, or, in the cases of Brazil and Turkey, the establishment of local companies with minority stakes owned by foreign companies.

Now many of these governments are reevaluating industry protection policies and reviewing policy options. One reason for this is that the operating companies are frustrated by the high cost of locally produced equipment. Prices for locally produced foreign designs of digital switching equipment in Brazil, for example, typically cost more than twice the price of similar models available on the open market. In addition, technology transfer deals usually involve mature designs, so local producers typically lock into older generations of equipment, including first or second generation digital designs. In developing countries where the industry is state−owned, these impediments are compounded by the inefficiencies of an excessively bureaucratic management structure and lack of incentives to perform. Long decision−making processes result in even less responsiveness to new technological developments. For governments that consider a modem, ubiquitous telecommunications infrastructure to be of vital national interest, the pressure will increase to liberalize procurement. The technology and cost gaps between locally produced and imported designs are likely to widen. Consequently, liberalization of imports and production is expected to proceed steadily.

However, developing countries that represent large markets for telecommunications equipment may have more leverage to extract concessions from foreign suppliers as they scramble for global market share. Governments may hold out for technology transfer of state−of−the−art designs, as well as concessions on component costs. For Brazil, India, Korea, and other countries trying to develop a globally competitive telecommunications industry, the changing economics will make the goal increasingly difficult to reach. Only the largest of the world's telecommunications manufacturers—perhaps no more than five companies in total—are attempting to compete in all facets of the industry. Industrial policies in these countries are expected to adapt the strategies of the hundreds and thousands of competitors in the industry by specializing in specific product or technology areas.

Indigenous suppliers have the most to gain by focusing technology development on markets underserved by global competitors. The potential for development of low−cost, low−capacity, and low−energy−consuming technologies for thin−route and remote−area voice and data communications is enormous. Independent suppliers in developing countries will have more opportunity for success in these pursuits than to try to duplicate major state−of−the−art products available on the world market.

Finally, some countries may opt for a strategy to expand basic telecommunications services while maximizing national employment. The argument here is that the social welfare benefits of expanding basic analog services to the masses outweighs the efficiency gains of developing high−speed, state−of−the−art networks for business and government sectors of the economy. This strategy would mean local production of more mature technology with strict import restrictions. The challenge for industry in these countries will be innovating in low−cost systems without being able to take advantage of advances in electronic technology.

Notes

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PART II—
EXPERIENCES OF ADVANCED INDUSTRIAL ECONOMIES

7—
The U.S. Electronics Industry

Ralph J. Thomson

The U.S. electronics industry—the world's largest—has been the pioneer and historic leader for the global electronics sector. Measured in terms of output, technology base, innovation, investment, and employment, the United States occupies first position. At the same time, the technological and global market supremacy enjoyed by the U.S. industry in the 1950s and 1960s has been under assault over the last two decades by foreign competitors who have identified electronics as vital to their own national economic destinies. Particularly in the area of exports and growth rates, U.S. leadership in electronics has undergone serious challenges, notably from Asia, especially Japan.

The United States in 1990−91 continued to have the world's largest electronics manufacturing sector, commanding approximately 35 percent of world output. Japan, with 27 percent, and the European Community (EC), with 24 percent, were the second and third electronics powers in terms of production, with the rest of the world achieving a 15 percent share. If accurate data from its overseas facilities were available and taken into account, the U.S. electronics industry would show an even larger production share worldwide. However, in terms of growth rates since 1984, the United States has fallen to last place among nine electronics−intensive countries, a downward trend that is only partially mitigated by the fact that the other countries were growing from smaller bases.

The shifting world electronics trade balance is evidence that a number of competitors are catching up and—in the case of Japan—surpassing the United States in certain industry categories. From a surplus position of $7.3 billion in 1980, the overall U.S. industry had registered its worst deficit position of $13.1 billion by 1986, improving to a $2.7 billion deficit level by 1990, but deteriorating again to $5.2 billion in 1991. The U.S. electronics trade balance with Japan worsened more than 650 percent during the same period from a deficit of $3.9 billion in 1980 to $20 billion in 1988, improving slightly to $18.4 billion in 1990, but increasing to $19.3 billion in 1991.[1]

This electronics sectoral deficit represents 45 percent of the total U.S. bilateral trade deficit with Japan and almost 20 percent of the total U.S. global trade deficit. Without the approximately $20 billion bilateral deficit that has persisted with Japan since 1986 (the volume of Japanese electronics exports to the United States is over three times that of U.S. companies to Japan), the U.S. electronics industry would otherwise enjoy a strong positive global trade balance rather than a marginally negative position. In short, U.S. electronics industry leaders emphasize that if U. S. firms were half as successful in the $150 billion Japanese electronics market as they are globally, U.S. companies would augment their sales by some $15 billion annually—and raise their global market share by two percent.[2]

As it is, U.S. producers of a broad range of electronics manufactures and services have been faced with a steady decline of their world market shares in the past decade—from semiconductor materials and manufacturing equipment to the resulting chips and end systems utilizing such components. In 1980, U.S. manufacturers commanded a 53 percent share of global semiconductor production, 75 percent of semiconductor processing equipment, and 70 percent of computer systems. By 1991

those shares had been reduced to 44 percent, 47 percent, and 60 percent respectively, with Japanese firms garnering most of these lost shares. In the aggregate, despite annual increases in sales from 1985 through 1989, the U.S. share of the world market for electronics products and services dropped from 64.5 percent to 50.5 percent, with a resulting estimated loss of $105 billion in annual sales. During the same period, the U.S.−based share of global production fell from 52 to 34.9 percent.

The United States also continues to harbor the world's largest electronics market, with a 38.2 percent share of world consumption in 1989 (declining from 47 percent in 1985). The EC and Japan follow with 26 percent and 19.4 percent, respectively. Again, a number of foreign markets are growing more rapidly, with the United States occupying last place in terms of growth. Of note, Japan has now become the largest market for semiconductors ($20.9 billion versus $15.4 billion in the United States), mirroring its strong growth during the past decade in production of electronics end−manufactures, especially consumer electronics.

And yet, in terms of production, exports, innovation, and employment, the U.S. electronics sector has become the major growth area of the U.S. economy. According to the U.S. Department of Commerce (DOC), in 1990 the industry supplied about $300 billion in products from its U.S.−based plants; approximately $70 billion of this output was exported ($71.6 billion in 1991).3 Using a slightly more expansive definition,4 the American Electronics Association (AEA) estimated that domestic sales of U.S. electronics companies during the 1980−90 decade rose from $127 billion to $306 billion ($310 billion in 1991). In that same period, worldwide sales of U.S. companies increased from $190 to $445 billion (over $460 billion in 1991). Worldwide electronics production from all countries and companies totaled $751 billion. By either measure, domestic sales of U.S. electronic manufacturers have almost trebled in the past decade and have experienced consistent yearly growth during that period.

With domestic employment of 2.39 million primary or direct employees (December 1991), the United States possesses the world's largest electronics work force, although electronics employment in some other countries (for example, Japan, the Republic of Korea, and certain Asian nations) is growing more rapidly. Worldwide direct employment of the U.S. electronics industry (including foreign plants of U.S.−based companies) is approximately 4 million primary jobs. The U.S. electronics industry provides more jobs than any other manufacturing sector in the U.S. economy—three times more employees than the U.S. automotive manufacturing industry and nine times more than the basic steel industry. It is conservatively estimated that the industry also provides secondary and tertiary employment of some 4 million jobs to people who support and service U.S. electronics firms. According to the AEA, "one of every 20 jobs in the U.S. is in electronics or an industry that wouldn't exist without electronics."5 The U.S. electronics industry directly employs over 9 percent of the U.S. manufacturing work force, and has grown at an average of nearly 3 percent annually since 1977. During the past 15 years, the U.S. electronics industry has created more than 1.3 million new primary jobs, over half a million in the period from 1980 to 1989.

On the other hand, domestic employment in the U.S. electronics industry has demonstrated no growth for the past two and a half years. Indeed, since mid−1989, the industry has lost 210,000 jobs. If the robust U.S. software subsector is removed from the total, U.S.−based employment dropped by approximately 300,000−100,000 in 1991 alone. In contrast, during the past several years, Japan's electronics employment has grown from 1 million to 1.8 million workers, although this growth has been halted and probably reversed in the steady contraction of the Japanese economy and slowdown in domestic and global electronics demand experienced during 1990−92. The year 1992 began inauspiciously for U.S. electronics workers and management with the loss of a further 40,000 direct jobs during the first quarter.

Importance and Contributions of the Industry

Innovation

The U.S. electronics industry is the lead sector in U.S. innovation measured by the number of patents granted per year. Latest available data from the U.S. government indicate that in 1986, it received 36 percent of all U.S. patents and conducted 20 percent of all U.S. industrial research.

New Firm Creation

The U.S. electronics sector is a major source of new firm creation and is characterized by a high percentage of small companies. According to the DOC, from 1977 through 1991, the number of electronics−related manufacturing firms trebled to over 25,000. Companies with assets below $10 million made up 95 percent of this total, highlighting the predominance of small, entrepreneurial companies

within the U.S. electronics family—themselves a major source of innovative processes and products. It is noteworthy that in this same time period, U.S. software firms increased from 1,900 to nearly 40,000 with a total of 420,000 primary, secondary, and tertiary employees.[6]

Production and Productivity

The U.S. electronics industry has paced the overall economic well−being of the country by providing and sustaining an average growth rate of 11 percent since 1977 (more than twice the rate of the automotive and chemical sectors, and three times that of textiles and wood products). Only the aircraft industry had a growth rate comparable to electronics—albeit at shipment levels one−third those of the electronics sector ($75 billion versus $300−plus billion).

Gains in industry productivity during the 1977−86 period were substantial. Value added per production worker hour increased by 2.5 times in electronics versus the doubling of this index in all U.S. manufacturing, which leads the world in overall productivity.

Trade

U.S. electronics companies have registered major increases in the export arena over the past decade. The U.S. electronics industry exports a high level of its production—almost 25 percent industry−wide, with a substantial number of companies achieving 40−50 percent levels. The value of U.S. electronics exports has increased at an average rate of 18 percent per year since 1977, reaching $71.6 billion in 1991 (Japanese electronics exports rose to $76.0 billion in 1991). This rate widely out−paces all other major U.S. industry sectors, including the related high−technology aircraft industry.

Source of Key Products

The U.S. electronics industry is the toolmaker for basic U.S. industries and for a broad range of other industrial and service sectors, providing products and services critical to their productivity and global competitiveness by providing state−of−the−art equipment and processes. U.S. manufacturers are heavily dependent upon sophisticated instrumentation, advanced communications sys−terns, computers, and software to lower their costs and improve their efficiency. Most U.S. companies incorporate electronics technology into the design, manufacturing, marketing, and servicing of their products. The U.S. automotive sector, for example, has virtually trebled the value of its electronics componentry since 1952—now constituting more than $1,000 to $2,000 of the manufacturing cost of the average car.

The huge U.S. service industry sector has also been transformed and strengthened by electronics technology. Financial institutions, transportation and legal firms, and research institutes are heavily populated by electronic business equipment, telecommunications networks, advanced computers, and software for quick−response, geographically−dispersed operations.

The U.S. electronics industry has provided a critical contribution to U.S. national security, to the country's massive defense sector and to the West−em alliance system—especially since the U.S.−Western military advantage of the post−World War II period has been based on technological superiority, not weapons quantities. The dominance of electronics technology in the recent Persian Gulf War was dramatic and ultimately decisive. With the end of the Cold War and the dissolution of the former U.S.S.R., the previously huge U.S. buildup in military−related electronic systems and research provides at once a major opportunity and a bedeviling problem: on the one hand, the opportunity to turn to commercially viable production and a hoped−for societywide "peace dividend," and on the other hand, the problem of undertaking widespread, systematic industry conversion without severe work force and technological dislocations.

Major Characteristics of the U.S. Electronics Industry

Capital Intensiveness

The U.S. electronics industry's capital requirements exceed all other manufacturing sectors by a significant margin. Despite the industry's status as the largest U.S. manufacturing employer, the percentage of production workers has declined steadily in recent years because they have increasingly been replaced by the automation required to maintain the industry's global competitiveness relative to price, quality, and time−to−market factors. Indeed, for most U.S. electronics products, direct labor costs now represent only 5−10 percent of total manufacturing costs.

It is also noteworthy that the earlier large−scale out−migration of U.S. electronics jobs to Southeast Asia and Mexico has been diminished, and in certain instances, even reversed in the late 1980s and early 1990s. Labor cost advantages, which may still exist overseas, have been partially balanced by higher administration, shipping, and inventory

costs, as well as by lower productivity in certain newly industrialized countries (NICs).[7] The relative decline of the U.S. dollar and U.S. labor costs have also played roles in this "return" phenomenon although the Mexican *maquiladora* manufacturing activity and heightened prospects for low−rate Mexican labor under a potential North American Free Trade Association (NAFTA) are leading to renewed examinations.

R&D−Intensive Nature and Short Product Life

The electronics sector leads the U.S. economy in the amount spent on research and development (R&D) efforts and as a percent of sales. From 1977 to 1987, representative members and types of U.S. electronics companies more than doubled their rate of R&D expenditures, in the process accounting for 20 percent of the all−industry U.S. composite. Higher R&D outlays of U.S. electronics companies (7.9 percent in 1987) is a consequence of the short product life cycles characteristic of the industry and the resultant requirement for rapid product introductions. It is no longer unusual for U.S. electronics companies to achieve a significant portion of their revenues from products that are less than five—or even one or two—years old. Thus, even in times of slumping markets such as have been experienced in the late 1980s and early 1990s, the industry expended $19.9 billion, or approximately 7 percent of revenues on the vital R&D function in 1990.

The Industry as a Chain of Interdependent Links

The U.S. electronics industry is made up of a chain of interdependent links (most strong, a few relatively weak), ranging from the upstream materials and semiconductor equipment subsectors through semiconductor manufacturers and circuit board makers to downstream computer builders, instrument makers, software houses, and systems integrators. These individual subindustries within the U.S. electronics sector are inescapably linked, both technologically and financially.

U.S. computer, telecommunications, and instrument makers have understood the importance of a strong domestic semiconductor industry to help them avoid overdependence on foreign chip suppliers. For example, given the highly integrated structure of the Japanese electronics industry, Japanese firms are often also their major competitors in end manufactures. These U.S. systems producers are now also sensitive to the fact that a vital U.S. semiconductor industry, in turn, depends on a healthy U.S.−based semiconductor manufacturing equipment subsector.

In 1990, Japan supplanted the United States as the leading producer of semiconductor fabrication equipment. In 1979, U.S. companies commanded just under 80 percent of the global market; Japan not quite 15 percent. By 1990, Japan had moved to a 49 percent market share, with the United States receding to approximately 43 percent. U.S. wafer fabrication vendors rebounded to a 47.1 percent level in 1991 with Japan dropping to an approximately equal 47 percent share that same year.8

Any holding back by Japanese semiconductor manufacturing equipment firms of timely exports of new generation machinery to U.S. semiconductor producers could provide Japanese chip manufacturers with a 6−12 month head start. In the highly time−and technology−sensitive semiconductor business, where new generations of fabrication methods move through the industry every two to three years, even a six−month delay could cost a U.S. company most of its profits for one complete generation of semiconductor production, setting in motion a vicious cycle, which threatens to erode its future competitive position.

A recent report (September 1991) from the U.S. General Accounting Office (GAO) (the auditing arm of Congress), which indicated that 22 of 61 U.S. electronics companies interviewed complained in at least one instance that Japanese suppliers of the most advanced components and manufacturing equipment had delayed deliveries by six or more months after their deliveries to Japanese customers, which caused them to fall behind in the technology−to−market race. Three companies said that they were unable to manufacture key products, one firm claimed to have lost $1.4 billion in sales, and one small computer company said that it was "essentially out of business" because of its inability to obtain high−quality advanced screens for its laptop computer line. However, the GAO stopped short of charging Japanese companies with deliberate discrimination.9 The overreliance points holds, though other U.S. manufacturers did not support the findings.

Global Production and Marketing

From their beginnings, U.S. electronics firms have had a significant overseas presence throughout the world as major manufacturers, employers, and exporters. Fully one−third of U.S. company sales and over 40 percent of U.S. company employment is overseas. Computer systems provide a striking example of such strong foreign positions. U.S. overseas investment in 1986 was the source of more than 60 percent of the value of U.S.−company computer shipments to Japan and the combined markets of the Federal Republic of Germany, the

United Kingdom, France, and Italy. Less than 40 percent of U.S.−firm computer shipments were represented by exports from actual U.S. territory.10 In a world increasingly characterized by functional borderless economies, the U.S. electronics sector has become in many respects a borderless industry.

Collaboration

From its inception, the U.S. electronics sector has been characterized by limited collaborative entities entailing both domestic and foreign linkages to firms with complementary product, research, manufacturing, or financial lines. The number and complexity of such alliances involving U.S. electronics partners has increased dramatically in the past several years, reflecting several key factors in today's electronics R&D, production, and trade. Chief among them is the rapid growth of financial, human, and technological resources required to research, develop, and bring to market complex new electronics products and processes. For example, a new semiconductor fabrication facility for advanced chip products currently demands an investment of between $250 and $500 million, depending on the specific device and technology phase. This level of outlay is expected to rise to $800 million to $1 billion by the mid−1990s in view of the relentless drive toward new manufacturing technologies that involve shrinking feature sizes and submicron line widths. The recent IBM−Siemens joint investment of approximately $1 billion in a new semiconductor fabrication facility for 64 megabit DRAM memory production is an example.

In the past several years, U.S. domestic high−technology−related consortia alone have been forming at a rapidly accelerating pace (over 100 such groups by 1990). This represents only a small portion of U.S.−domestic and U.S.−foreign alliances being struck with rising regularity under several formats: joint ventures in R&D, manufacturing and sales, distribution and marketing agreements, technology and manufacturing licenses, localization or adaptation, and outsourcing arrangements to obtain needed foreign−developed parts and components. Reasons given by some 455 U.S. electronics executives for alliance with other firms are given in Table 7.1.

It should also be emphasized that U.S. electronics companies have frequently been required to form such cooperative ventures overseas in order to penetrate foreign market barriers. Further, as foreign electronics companies have become more capable of supplying advanced products that feature competitive technologies, prices, and quality, U.S. electronics companies have come to depend on alliances with such companies (sometimes heavily, as in the case of DRAMs or flat−panel displays for personal computers and work stations) to remain competitive in local and global markets. Often, such linkages are bought at the long−term cost of diffusing U.S. technology to foreign firms, many of which then become significant competitors in the U.S. and world marketplaces. The compelling logic of these alliance−inducing factors has also led to marriages (both domestic and international) between seemingly strange bedfellows—fierce competitors who nevertheless see greater benefits in collaboration. Recent surveys of U.S. electronics companies focusing on the relative merits and demerits of cross−border relationships have demonstrated the depth and breadth of support within the U.S. industry for foreign partnerships of every kind.

According to a Stockman & Associates study in 1991 of 94 large U.S. high−technology companies, nearly two−thirds self−rated their global partnerships as successful. Such strategic partnerships "amount to a new solution for an old problem: namely finding the right balance of vertical integration so as to safeguard and exploit a firm's proprietary advantages, while retaining sufficient flexibility to access superior price or performance capabilities offered by merchant component or marketing specialists."[11] Such arrangements, if well conceived and managed, provide the advantages of an effective new hybrid form, that is, virtual vertical integration.

The Borderless Laboratory

Shared burdens have magnified the inexorable globalization of technology and led to the recent rise of the borderless laboratory. Just as U.S. elec−

Table 7.1
Motivation for Strategic Alliances by U.S. Electronics Executives

Motivating factor	*Percentage of executives*
Access new markets	82
Enhance marketing, distribution, and sales	76
Access foreign markets	64

Access new technology	50
Improve product development	46
Defend market share	35
Access capital	31
Limit strategic risk	30
Gain cost advantage	28
Diversify	22

Source: Electronic Business and Ernst and Young.

tronics companies and their foreign competitors once moved their manufacturing operations overseas, they are now increasingly positioning considerable portions of their research and product development throughout the world, thus transforming the creation of technology into a functional activity that transcends national frontiers. This trend is gathering momentum, with almost 1,000 new transnational alliances by U.S. companies or investments by foreign companies in technology start−ups since the mid−1980s in the United States alone, not to mention numerous joint marketing, licensing, and cross−border mergers and acquisitions (M&A) in the United States and throughout the world.

In the United States, even those who worry about the country's best ideas being bought by foreign entities for fire sale prices or smuggled away for commercialization overseas, acknowledge that the United States no longer holds a near monopoly on advanced technology. Just as the earlier movement of U.S. manufacturing activities abroad was originally targeted mainly at accessing low−cost foreign labor, the trend to cross−border research and development is based on acquiring foreign technology. U.S. companies are thus concentrating not only on the transfer or sale of electronics technology abroad—a 20−year movement that has often led to counterproductive asymmetries in technology−based trade and investment—but also on acquiring substantial foreign technology (when available) for commercial exploitation in the United States and in global markets. Two notable recent examples of this phenomenon are the growth of Intel's strong leadership in flash memories based on technology developed by Toshiba and on IBM's joint venture activity with the same Japanese company in technology transfer and joint manufacturing within the active matrix flat−panel display field. Both are vital components of next generation computing.

U.S. Industry Leadership: Strengths, Weaknesses, Challenges, and Opportunities

It is now appropriate to examine briefly the overall U.S. electronics industry's profile in terms of the crosscurrents of abiding strengths and weaknesses, lost and regained ground, new ground, and current resurgence. Evidence in the late 1980s of weakening industry positions (that is, higher foreign growth rates in production, consumption, and employment; and a deepening trade deficit and an eroding technology base mirrored in a diminishing share of global and domestic markets) are balanced by indicators of strength and vitality—new firm creation, extraordinary innovativeness, growth in shipments and employment, and expanding worldwide production and marketing base.

Technology Assessment

A general consensus on U.S. industry competitiveness is evident in the numerous analyses and critiques of technological strengths and weaknesses of U.S. versus foreign electronics industries. For example, in preparing their report, which identified critical technologies upon which the U.S. computer industry will depend into the twenty−first century,[12] a group of chief technology officers (CTOs) found that the United States is maintaining its competitive advantage in areas of technology that depend upon creativity and are less capital intensive. These subsectors include software engineering, applications technologies, processor architectures, and some elements of microelectronics. On the other hand, the chief group of technologists concluded that U.S. industry lags in capital−intensive technologies, such as fabrication equipment and facilities for ultra−large−scale integration, some elements of microelectronics, and manufacturing. At the same time, they emphasized their optimism that a focused U.S. industry, supported by high−impact public policy, has the capability to improve its current performance significantly in key technologies. Their conclusions mirrored those of other authoritative industry observers.

In their examination of 16 categories of critical technologies, the CTOs assessed the U.S. computer industry's present competitive status vis−à−vis the rest of the world, then projected the industry's future over the next 5−10 years in relation to its foreign competitors under two sets of assumptions: (a) that the U.S. industry maintains its current course and (b) that it operates under optimal conditions that in some cases will involve corrective or augmented measures. The chief technologists reached a consensus that the U.S. industry continues to have the capacity to substantially improve its current competitive position in every technology category.

U.S. Industry Resurgence

In a number of areas of recent U.S. decline measured in terms of market share and technology leadership, U.S. electronics firms and cooperative ventures are entering a period of apparent resurgence. Perhaps the most dramatic changes are taking place in the area of greatest U.S. industry loss of the past two decades—the consumer elec−

tronics sector. For the first time since Japan severely dislodged the U.S. consumer electronics industry in the 1990s, U.S. firms have an opportunity to stage a comeback in this vast $32 billion U.S. and $100 billion global market. Indeed, highly competitive U.S.−designed and manufactured consumer electronics products are already making their way, many of them made possible by the underlying technology of digital signal technology (DSP), created and dominated by U.S. firms.

DSP−based technologies enable the wholesale penetration of electronics into large numbers of consumer applications in the home, automobiles, airplanes, and almost any applications setting. DSP chip technologies enable the translation of familiar analog signals (such as voice and image signals) into the discrete digital language of computing where the signal can be manipulated in a variety of fashions impossible in analog format. For example, digitized radio signals can be greatly compressed to take up less space on the spectrum. Digital systems can pack three or more telephone conversations into the same space of the single conversation possible under analog technology. Similar DSP−based compression of video signals can bring hundreds of cable television channels into the home, hotel or office.

Among recent tangible product manifestations are tapeless telephone answering devices rivaling high−end voice mail systems, which record messages on a transmission of color video images over regular telephone wires; the world's lightest and smallest cellular phone; the first low−cost, mass−market multimedia home computers, which will play music and video, and which will speak, send facsimiles, and receive electronic mail. Within the next few years, U.S. firms will have the opportunity to re−enter the largest consumer electronics segment: television. U.S. digital technology provides the opportunity for leap−frogging longstanding Japanese efforts to develop and dominate the high−definition television (HDTV) future based on increasingly out−moded analog systems.

Although Japanese manufacturers dominated the emerging DSP chip market in the early 1980s with an initial 93 percent share, by 1991 U.S. firms reached this same level of market ownership, with the Japanese dropping to a mere 6.5 percent—one of the most marked losses for that country's semiconductor sector. Explanations for the drop vary, but it appears that as the software algorithm and chip design parameters grow in complexity, Japanese companies experienced increasing difficulty. With the worldwide DSP semiconductor device market surging by nearly 30 percent a year (three times faster than the overall semiconductor market), DSP chip sales are estimated to reach $1.1 billion in 1992, growing to $4−5 billion in 1996. Major U.S. DSP manufacturers, such as AT&T, Texas Instruments, and Motorola, are doubling and tripling their current production.

U.S. dominance in DSP does not guarantee a major U.S. revival in consumer electronics. Large Japanese consumer manufacturers who produce their own memory and other semiconductor devices are currently experiencing unusual delays in time to market, due in large measure to their lack of in−house DSP capability. The United States will have to rebuild its consumer electronics manufacturing infrastructure to take advantage of this window of opportunity.

Other evidences of re−emerging U.S. consumer electronics opportunities include (a) digitized preservation of photographs on CD−ROM disks via work station scans and transfers of negatives (similar products are being planned for home use); (b) technologically sophisticated, but easy−to−use educational products, including computers for children; (c) new devices that enable interactive home television sets for banking, shopping, and data exchange with pocket computers; (d) intensive development of hand−held pen−based personal digital assistants (PDAs).

If current trends continue, U.S. computer firms can be the world's principal producers of multimedia personal computers. A major undertaking in that arena was accelerated by the recent alliance of IBM and Apple, which are pooling their considerable resources in order to develop advanced multimedia software. U.S. semiconductor firms are currently providing low−priced add−on boards capable of upgrading existing personal computers to multimedia machines. It is estimated that by 1995, over 1.5 million multimedia personal computers (PCs) will be sold annually in the United States alone, with another 750,000 PCs upgraded to multimedia machines through enhancement boards. Over 85 percent of these multimedia PCs are projected to be either U.S.−made or designed.[13]

Software, where the United States enjoys an estimated three− to five−year lead in spite of the major Japanese energies, resources, and software factory approaches targeted for this sector. In 1991, the U.S. software industry received $21.9 billion, or 52 percent, of its revenues from foreign sales. Continued creativity has led to new U.S. strengths in advanced, relational object−oriented, and data base disciplines, as well as applied−intelligence programming. As the software aspect of information systems is becoming increasingly vital, even dominant, this augurs well for strength of the U.S. industry.

Mini−disk drive components, such as the 1.3−inch drive that holds 20 megabytes of data for pen computers, personal digital assistants, laser printers, medical equipment, and voice mail messages on cellular telephones, presages continued domination of the market, although almost all are manufactured outside the United States.

New technologies are employed in the production of active matrix liquid crystal display (LCD) flat panels. These technologies and a rising number of U.S.−industry alliances, such as the new Xerox, AT&T/NCR, DEC, and David Sarnoff Research Center consortium, could challenge current high−cost, low−yield processes employed by Japanese industry, which currently holds a near monopoly in the field. The Xerox−led alliance plans to establish commercial U.S. production of next−generation flat panels, thus providing a U.S. alternative to Japanese dominance.

Major Issues Confronting the U.S. Electronics Industry

With the entire sector, from materials to systems, under systematic challenge from foreign enterprises and their supporting governments, there is a growing movement toward focused action on the part of the U.S. government and the U.S. electronics industry, both separately and jointly, to deal with a cluster of core issues involving policy initiatives and public−private cooperation. This section will briefly examine these critical items, their impact upon the nation's electronics community, and key prescriptive actions to fortify the industry's position.

The Cost and Availability of Capital

Although the cost of capital is an important competitive element for all industries, it is a critical component for the capital−intensive electronics sector. Not only overall growth of net investment is affected, but perhaps more importantly, the competitive velocity with which the industry can stay current and move to the leading edge. There is ample evidence that the U.S. electronics industry was burdened during the 1980s with a real cost of finance capital more than double that of the Japanese industry[14] and at least 30 percent higher than that of the Federal Republic of Germany.[15] Seriously disadvantaged vis−à−vis Japanese electronics companies in the net real cost of capital for equipment and fixed assets, U.S. enterprises also felt negative effects in the vital area of R&D. One key indicator was the rate of investment in manufacturing and productivity growth. According to 1987 OECD data, gross investment per worker in manufacturing in the United States was just over 50 percent of that invested by Japanese firms.[16]

The cost—and availability—of capital in the United States has been affected heavily by the massive U.S. federal budget deficit and a U.S. tax structure that encourages borrowing and consumption rather than savings; hence a smaller capital pool available for investment. Whatever the root causes, the significantly higher cost of U.S. capital in the 1980s exerted a negative rippling effect along the entire spectrum of business functions from R&D to marketing and service.

In the early 1990s, a substantial easing in the cost of U.S. capital combined with major upward rate adjustments in Japan. The dramatic decline of the Nikkei index and attendant monetary policy decrees of the Finance Ministry served to level the field of capital expansion for the U.S. and Japanese electronics industries. Whereas Japanese companies historically have been in a position to outspend their foreign competitors in research, new plant, and equipment for leading edge technology through the simple advantage of less costly capital, by 1990 a soaring Japanese discount rate of 6 percent actually led to a slight drop in capital spending. With the Federal Reserve Board's decisive cut in the U.S. discount rate to 3.5 percent in December 1991 and further to 3.0 percent in June 1992, the U.S. level dropped below Japan's rate for the first time in many years. In March 1992, Japan felt compelled to reduce its discount rate to 3.75 percent in order to spur its overall economy and to assist the Japanese high−technology sector in its quest to achieve market dominance.

Across the Atlantic, capital costs are also rising as a result of a steadily higher rate occasioned by the massive outlays required for German unification and the rebuilding of the former German Democratic Republic. With the U.S. and Japanese (and European) economies experiencing virtual capital cost equality in the early 1990s, there are signs that the decade ahead might usher in a much−needed U.S. investment revival, especially after the U.S. economy comes out of its current recession.

DRI/McGraw−Hill data show that in the 1980s, total fixed investment in the United States as a share of output averaged only 15 percent, placing U.S. investment behind that of all major trading partners (the United Kingdom, France, the Federal Republic of Germany, Canada, and Japan).[17] Thus, to some economists it appears that because the United States has underinvested for so long, and at

such a cost to its competitive position, capital spending will rise substantially in the 1990s, simply because it must in order to compete.

However, capital spending investments are not determined by capital cost alone. The U.S. economy is still burdened with a low rate of savings, which the DOC indicates further dropped from 7.5 percent of disposable income in 1981 to just 2.9 percent in 1987. Even if the accumulation of U.S. capital gains income is added, the affluent in the United States who possess substantial liquidity to invest have failed in recent years to fulfill their traditional roles as funders of productive investment. At the same time, the composition of U.S. government spending in the 1980s shifted increasingly toward consumption and military expenditure and away from civilian and industrial investment. It remains to be seen if the reduction of consumption levels driving the U.S. recession and pared military outlays will usher in a needed correction.

Adding to their finance capital difficulties, the U.S. electronics sector and its sister industries continue to be hostage to the injurious crowding out of the ever−ballooning federal deficit. The already alarming deficit of the 1980s is moving toward projections of ongoing $300 billion or higher annual deficits well into the next century, if current practices are not continued. At these levels, the budget deficit is not merely a national embarrassment, but a persistent disease that is eroding the savings, investment, and long−term growth of the overall U.S. economy—with acute consequences for its heavily capital−dependent high−technology sectors. Observers fear that even as U.S. private investment attempts to rise with a recovering economy, government borrowing will consume the bulk of the capital supplies.

Traditional overseas investors are no longer in a position to provide sufficient sums of new capital to U.S. industry as in past years. U.S. firms and governments that benefitted enormously in the 1980s from Japan's financing of much of the cumulative $2.3 trillion in U.S. budget deficits are faced with the need to adjust to new realities. Pressured by its growing financial crisis and accelerating recession at home, Japan has actually withdrawn almost $60 billion since 1989. Already in the first quarter of 1992, Japan *imported* capital at an annualized rate of $38 billion. Japanese bidders who once bought up over 40 percent of U.S. Treasury bonds now take on 10 percent or less. European capital will increasingly be directed inwardly and to former Soviet bloc lands. The German economy and government are especially hard−pressed by the extraordinarily high costs of rebuilding the ravaged economy of the former German Democratic Republic.

A recent American Electronics Association (AEA) survey highlighted the critical capital availability problem faced by its membership, especially small companies with revenues of less than $50 million. Of 126 companies queried, 62 experienced difficulty obtaining bank financing, and 50 were actually denied financing. A further yearly study of financing by 100 major U.S. banks, for firms in the $50 million to $300 million revenue range, revealed that over 90 of these banks were willing to lend to high−technology firms in 1990. By 1991 this number had dropped to 34, and by 1992 to fewer than 10 banks.[18]

Finally, although the cost of short−term debt has been sharply reduced in the United States by action on the part of the Federal Reserve, long−term rates remain high. This poses severe problems for U.S. electronics companies, which are typically required to invest large sums in long−term R&D and complex plant and equipment.

The Role and Impact of Venture Capital

One of the key ingredients in the early growth of the U.S. electronics industry—the highly supportive venture capital community—has been partially neutralized by changes in attitudes and recent funding patterns of that sector. Together with private investors, the venture capital community has traditionally provided the major financing support for start−ups, the funding source behind much electronics innovation and commercialization in the United States. Since the high point in 1984, when U.S. hardware and software companies received more than 50 percent of such investments, venture capital pools have become increasingly selective and cautious in their relations with U.S. electronics companies and have shifted substantial funding to other industries. Furthermore, U.S. venture capitalists typically demand high percentages of ownership and returns on investment, which further limits the number of young companies that wish to avail themselves of such financial sources.

Thus frustrated, increasing numbers of U.S. electronics start−ups and mid−range fast−growth companies have turned to well−financed foreign investors (especially those from Japan, Taiwan (China), Korea, and Europe) who have in the past been willing to accept considerably lower rates of return and ownership percentages rather than

U.S. funding sources in order to gain access to U.S.

strengths in innovation. Of course, such seeming largesse is not without its price, the one−way transfer of valuable advanced technology to potential or declared competitors.

As the decade of the 1980s opened, commitments to venture funds in the first year totaled $681 million. With the major reduction of U.S. capital gains tax rates in 1982−83 and the active market for initial public offerings (IPOs) and resultant unusually high returns, U.S. venture capital funds became bloated in the mid−1980s. Commitments reached a pinnacle of $4.7 billion in 1987. After years of annual returns averaging more than 20 percent (with a number of individual funds achieving 70 percent), U.S. venture capital collectively lost an average of 3.8 percent annually from 1986 to 1990. In turn, commitments to venture funds dropped to $2.9 billion in 1983, $1.8 billion in 1990, and $1.3 billion in 1991.

Recent dramatic upward movement in small company stocks and IPOs have strengthened the returns of existing U.S. venture funds and have led to the establishment of new venture capital pools with expectation of a compound annual return of 25 percent over the next several years (1991 saw estimated returns of 10 percent). This rebound of venture capital funds is seen as a boon for the international competitiveness of U.S. high−technology enterprises, but the movement back to venture capital funds is not headlong. It seems clear that the excesses of the 1980s will not be repeated in the 1990s and that the U.S. venture capital community will be smaller, if nevertheless robust. According to one of the most respected venture capital sector leaders, "the industry can probably safely invest up to $2 billion a year. It cannot effectively manage $3 or $4 billion a year."[19] Indeed, the authoritative Venture Economics Group predicts that U.S. venture funds will attract approximately $2 billion in 1992.[20] It should be observed that new technological areas, such as biotechnology, are major competitors with the electronics industry for funds.

Although this reduced funding of venture capital firms has led to a new conservatism within the funding sector, it has also brought about a return to basic values and solid practices, including more thorough due diligence and management evaluation processes. Recent surveys by Coopers & Lybrand indicate that this more conservative approach does not presage fewer investments in solid start−up and growth enterprises nor a retreat from early−stage seed and incubator investments. At the projected $2 billion funding level, "deserving entrepreneurs with companies at all stages of development should find adequate access to capital. Even in this year of consolidation and caution, active (U.S.) venture capitalists will make nearly 400 investments in a wide variety of companies."[21]

Research and Development

The U.S. electronics industry, dependent on innovation for leadership (and ultimately, survival), leads the nation in levels and rates of R&D outlays. The U.S. government has played important roles in fostering the domestic electronics industry's development via tax policy, direct funding and procurement. For example, Congress introduced an R&D tax credit as part of the 1981 Economic Recovery Tax Act (ERTA) to goad U.S. companies toward increased R&D outlays and stimulated innovation. Although viewed as a mixed blessing by some (due mainly to the R&D credit's temporary benefits, which serve to prevent true long−term planning), Brookings Institution data indicate that U.S. R&D spending nearly doubled between 1980 and 1986 and that the R&D tax credit itself led to research outlays by U.S. firms 7 percent higher than would have been the case without benefit of the credit.

Aside from tax policy, most U.S. government funding in electronics−related R&D has been directed principally toward national security functions and military applications. In spite of some notable spin−offs into the commercial electronics realm in the early years (new materials, integrated circuits, supercomputers, and telecommunications), the predominant view holds that a defense−oriented R&D system is not an efficient conduit for generating marketable commercial products and processes. On the other hand, it is estimated that the rate of return on civilian R&D spending reaches as high as 50 percent per year if indirect benefits to the economy are factored in.

In the past decade, U.S. R&D expenditures, while registering significant increases to 3.0 percent of GNP, still include 30 percent dedicated to national security. Furthermore, the U.S. defense sector has claimed a share of scarce scientific and engineering manpower increasingly needed for commercial applications. By way of contrast, Japan's percentage of GNP dedicated to R&D efforts has also risen to 3 percent, with fully 98 percent of total outlays and by far the greater portion of its scientific and engineering community applied to purely commercial endeavors. As a result, Japan's corporate R&D growth rate has been up to three times greater than that of the United States, although U.S. companies still spend twice as much on R&D. Germany's R&D outlays were at a similar level, with 95 percent dedicated to civilian or commercial activity. It remains to be seen how

much redressing of this U.S. military−civilian asymmetry will be achieved through the peace dividend. After the collapse of the U.S.S.R., the end of the Cold War, and Western victory in the Gulf, nearly 60 percent of the $74.6 billion federal R&D budget is still earmarked for defense.

In its 1993 budget, the Bush Administration proposed increasing nondefense R&D spending by 7 percent to just over $30 billion and pushed the national weapons laboratories (the nine largest of which command $6 billion in budget and occupy the energies of 29,000 researchers and technicians) to focus more on commercially relevant research. To date, nonmilitary funding increases and commercial spinoffs have been very modest. Momentum appears to be gaining. For instance, early signs of movement are observable in the 1993 federal budget proposals, which earmark R&D expenditures of $803 million for high−performance computing and networking (including high speed data lines linking universities, government labs, and industry), $1.8 billion for advanced materials and processing, and $321 million for advanced manufacturing.

Still, the United States devotes a much smaller portion of the total R&D expenditure to civilian efforts than its chief rivals. U.S. high−technology firms spent $74 billion on R&D in 1991, which is a mere 3 percent increase when adjusted for inflation. The National Science Board reported in 1991 that total U.S. spending on research began to fall for the first time since the 1970s.22 Although the United States still leads the world in overall spending on scientific research, U.S. corporate R&D growth lags behind most foreign counterparts. According to a Standard & Poor's composite, the top R&D spenders in Germany devoted 6 percent of their sales to R&D, 5 percent in Japan, and 3.6 percent in the United States. More telling, in 1991 the United States spent only 1.9 percent of gross domestic product (GDP) on nondefense R&D (both private and public) compared with 3 percent for Japan and 2.8 percent for Germany.23 And it has been clear for some years that the Japanese electronics sector is outspending the overall U.S. electronics industry's R&D by almost two to one. This figure is closely watched because technological breakthroughs are the greatest spurs of growth in market share, wealth, jobs, and standard of living. Collateral issues of time to market for technological innovations must also be considered in the competitiveness equation.

In an effort to improve the effectiveness and real−world linkages of federal laboratories, the 1980 Stevenson−Wydler Technology Act mandated these laboratories to make their developed technologies available to the private sector for translation into new commercial processes and products. A variety of subsequent amendments to the Act have been formulated for the purpose of streamlining procedures leading to the foundation of cooperative R&D programs with private entities and to provide monetary incentives for the laboratories to transfer valuable technologies to the private sector.

In May 1992, a further step in this public−private cooperative direction was taken by the signing of an agreement between the organization of the 12 largest U.S. computer companies, the Computer System Policy Project (CSPP), and the U.S. Department of Energy (DOE) to take advantage of a new model made available by DOE in

March 1992 for individual high−technology companies to negotiate joint research with or obtain information from the U.S. national laboratories and the DOE on an expedited, simplified basis. The program, known as the Cooperative Research and Development Agreement (CRADA), has led to a half dozen arrangements between government and private industry, with approximately 20 more in progress.24

As reflected in data from the AEA, the great preponderance (some 70 percent) of U.S. electronics R&D has been underwritten by industry itself since the mid−1970s (see Table 7.2). At the same time, it should be noted that until recently, most U.S. electronics R&D performed by industry had been relatively uncoordinated and concerned principally with near−term goals. Encouraging, notable exceptions have been organized in the past decade, among them a number of programs involving a combination of public and private resources.

Table 7.2
Value of U.S. Electronics R&D by Source of Funding, 1977−86
(US$ billions)

Source of funding	*1977*	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*
Industry	4.6	5.4	6.4	7.8	9.0	10.7	12.6	14.8	16.0	15.8
Government	1.8	1.9	2.3	3.0	3.1	3.7	4.3	5.2	5.9	6.3
Total	6.4	7.3	8.7	10.8	12.1	14.4	16.9	20.0	21.9	22.1

Source: American Electronics Association, 1989.

In 1987, a unique public−private partnership, SEMATECH, was formed to assist the U.S. semiconductor industry achieve and maintain worldclass strength in semiconductor manufacturing. Fourteen of the United States' major merchant and captive semiconductor firms began contributing annual dues of $100 million, which has been matched by $100 million of annual federal funding. Although the original industry roster has been reduced to 10 major companies and federal funding in 1993 is projected to drop to $80 million, the consortium has achieved recognition for achieving the bulk of its technical objectives, which focused on the development of world−class parity processes in 0.35 micron integrated circuit geometries and associated new semiconductor manufacturing equipment and processes. Most importantly, in 1992, SEMATECH will have developed a U.S. source for each major piece of semiconductor manufacturing equipment including units featuring leading edge 0.35 micron manufacturing capabilities. It is likely that the Clinton Administration and Congress will approve some level of SEMATECH's continuation for another five years with a new emphasis on software modeling and simulation approaches to computer integrated manufacturing (CIM) on specific generic integrated circuit (IC) manufacturing processes. Full−system integration is now to be left to member companies. This is a major mission shift. At this point, industry observers credit SEMATECH efforts with a 20 percent increase in U.S. suppliers' share of the U.S. market and a 4 percent gain in worldwide semiconductor equipment markets.

The oldest of the United States' high−technology consortia—the Microelectronics and Computer Technology Corporation (MCC)—was chartered in 1982 by major U.S. computer and semiconductor firms, partially in response to Japan's Fifth Generation computer project. Its focal mission has been to strengthen and sustain the competitiveness of member companies through application−driven research, development, and deployment of innovative information technology. With a family of 22 corporate shareholders and 58 associates (corporate, government, and university), 450 employees, and a 1992 budget of $45 million, the consortium has been the recipient of 73 patents and has transferred over 200 technologies to member companies. Although some complain that MCC should have delivered more technology into the marketplace to justify the consortium's expenditures of several hundred millions of dollars, MCC membership is currently at record levels. Both small and large U.S.

electronics firms are engaged in a record number of research projects, and the consortium is spinning off several new corporate ventures based on MCC−developed leading edge software and hardware.

Time to Market

Finally, although widely acclaimed for their innovative research, U.S. electronics companies also have the reputation for being slower than their Japanese counterparts in time to market for R&D advances. In spite of the recent upsurge in attention within industry and academia to this disquieting phenomenon, many U.S. electronics firms remain at a competitive disadvantage in the design and implementation of manufacturing processes, which lead to timely product introduction. Most U.S. enterprises over the past decade have typically devoted less attention to innovations in critical competitive manufacturing processes, often viewing manufacturing as a linear exercise in which design and engineering are separated from production. On the other hand, Japanese and other Asian competitors tend to integrate staff and management in all functions and at all points of the spectrum, from design to manufacturing. This approach demonstrates a greater capacity to make incremental improvements in the manufacturing processes, which in turn results in substantially reduced production costs and higher product quality. The U.S. industry is addressing this shortcoming on a wide front.

Antitrust Laws

In recognition of the new realities of competition, some initial steps have been taken by the U.S. government to mold the antitrust code into an instrument which does not discourage cooperative R&D. In 1984, Congress and the president joined forces to craft the National Cooperative Research Act (NCRA) of 1984, which amended U.S. antitrust laws to permit joint R&D projects in the private sector. At the same time, the Act substantially reduced the incentive for antitrust suits by applying "rules of reason" and by reducing the previously prevailing treble damages threat to one of single damages if actual anticompetitive activity should be proved. Since the signing of that Act, some 125 consortia (including a representative number in the electronics sector) have registered with federal authorities. Without such legislation, the electronics industry's SEMATECH and MCC could not have come into being.

The 1984 Act does not address other pressing industrial organizational issues confronting the U.S. electronics industry. Although U.S. companies

may now more easily enter into joint efforts in the precompetitive research and development of new technologies, they must also be enabled to take the resulting new products into timely, cost−effective production of finished goods. As we have seen, the costs of necessary investment in new production equipment and facilities for complex electronics products increasingly pose difficult barriers for many U.S. companies acting on their own. For example, in an era of $250 million to $400 million semiconductor fabrication lines limited to 18− to 24−month product lives, even the large electronics enterprises today feel the need to combine resources,[25] In this pressing context, the real or potential risk of antitrust actions by private or public sector parties has had a chilling effect on the establishment of needed joint production operations.

Prompted in part by an increasing awareness of competitive pressure being felt by U.S. high−technology industries from Japanese and EC companies which operate under significantly fewer antitrust constraints on joint production ventures than U.S. enterprises, members of the 101st Congress proposed expanding the 1984 NCRA to cover joint production activities. In the spring of 1992, the Senate voted to relax antitrust laws for joint production facilities for semiconductor manufacturing and other high−technology ventures. A similar bill was introduced in the House of Representatives. Authors of the antitrust reform measure indicated their intent to reverse a pattern of products being invented in the United States but being produced largely overseas.

Corporate Financial Structures and Linked Business Cultures

The global electronics industries and their operations are set in an environment that requires the long view and long−term planning. Against this backdrop, the U.S. electronics sector, in spite of its many inherent strengths, suffers a set of disadvantages vis−à−vis many of its foreign competitors. Stockholder equity is a major source of funding for U.S. enterprises, including the country's electronics companies. It is a given that such primary dependence on the equities markets entails a requirement that short−term profits be maximized, thus engendering a financial culture where impatient capital is too often the dominant force. This, in turn, usually compels U.S. electronics companies to view a significant portion of their operations through a relatively short−term, often tactical lens.

On the other hand, many foreign electronics competitors—especially Japanese and other Asian firms—enjoy close relationships (even formal affiliations) with major banks and other financial and cross−holding institutions, along with the attendant high debt−to−equity ratios and lower capital costs and risks. This allows these foreign enterprises to take the competitively superior longer−term, more strategic approach to technology and overall business development. Such advantages to foreign electronics firms have consistently been demonstrated in their strategies, such as forward−pricing to gain global market share while U.S. enterprises, saddled with heavy equity commitments, are forced to concentrate more on short−term profitability at the relative expense of long−term operations and development of market share.

An instructive survey taken among U.S. and Japanese corporate leaders demonstrates rather dramatically the consequences of their disparate underlying financial structures and resultant differing business cultures and management priorities. As is shown in Table 7.3, Japanese executives place market share and return on investment in first and second place, while their U.S. counterparts are primarily focused on return on investment and share price increases, with market share in third place. Japanese executives position share price increases in last place, mirroring their limited dependence on stockholder equity.

Education and Training of the Work Force

No sector of a country's economy is more dependent on a skilled work force than its electronics industries. Without well−educated intellectual workers and a well−trained skilled production force, a nation's electronics companies cannot be competitive. The U.S. electronics industry historically has relied on a highly competent work force

Table 7.3
Ranking of Corporate Objectives: Japan and the United States

Corporate objective	*United States*	*Japan*
Improve market share	3	1
Increase return on investment	1	2
Accelerate product innovation	7	3
Rationalize production and distribution	5	4
Improve product portfolio	4	5
Increase equity ratio	6	6

Improve company's image	8	7
Improve working conditions	9	8
Increase share price	2	9

Source: *Kaisha* , by Abegglen and Stalk.

as one of its major advantages in international trade. However, a number of recent indicators have given rise to concern that this key element in past U.S. electronics successes is endangered.

The U.S. Department of Labor *Work Force 2000* , an analysis of the U.S. skilled work force situation, noted that regarding the industry demand factor, some of the fastest−growing job categories are found in the electronics sector. Computer and mathematical scientists, engineers, programmers and other software−related occupations,26 technicians, technology−related marketing, and sales and managerial positions are predicted to grow at an average rate of 46 percent compared with a 25 percent rate of growth for all U.S. occupational categories. These electronics industry job categories will require substantially higher−order skill development and education with emphasis on mathematics, science, languages, and communications.

The steady introduction of new technologies into the work place bring with them the requirement that workers continue to learn and gain skills throughout their careers. Although 80 percent of the U.S. labor force in the year 2000 are currently employed, most workers will be engaged in very different jobs by the end of this decade. The Business−Higher Education Forum estimates that at any one time, over 3 percent of U.S. workers need retraining to avoid becoming obsolete.27 And yet, according to Forum, the United States has seriously underinvested in the skill development of its workers. Only 25 percent of unemployment aid is directed to re−employment assistance—a percentage significantly lower than in competitor countries in Asia and Europe.28 Since every 1 percent increase in U.S. unemployment levels costs the government over $40 billion in revenue, skilled work force retraining brings compelling fiscal rewards as well.

Against this demographic and industry−demand background, trends in U.S. education show a disturbing picture—namely, a significant decrease in the number of students specializing in science and engineering. According to National Science Foundation estimates, by the year 2000, the United States will educate 600,000 fewer scientists and engineers than the country requires, although elements of U.S. industry are currently experiencing surpluses of selected types of engineers, reflecting a mismatch of skills and job opportunities. This long−term trend line cannot fail to lead to major international competitiveness problems for U.S. electronics enterprises.

One serious long−term implication of a U.S. engineering shortfall in human resources is linked to the fact that engineers create rather than redistribute wealth. "Their work increases the productivity rate, or output per worker hour, which is the ultimate determinant of a nation's wealth. Engineers intrinsically are wealth producers. . .the people who take science and render it into products. We can't exist as a total service economy. At stake, in short, is the nation's standard of living."29

If engineering shortages accelerate, it may lead to an exodus of some high−skill, value−added operations of U.S.−based electronics companies overseas where—ironically, for a nation which has been a high−technology training and education mecca for the world—more plentiful, secure sources of scientific, mathematical, and engineering human resources can be found. U.S. electronics industry associations have pressured the U.S. government for immigration reform legislation to permit foreign nationals who possess science and engineering skills to remain and work in the United States after completing their education at U.S. academic institutions if U.S. workers cannot be found. Since 40 to 50 percent of current graduate engineering students in U.S. universities are foreign nationals, Congress and the Bush administration approved legislation to extend work−stay visas to foreign individuals in such skill shortage areas.

A final warning flag for the U.S. high−technology sector is the fact that U.S. high school students compare unfavorably with their Asian and European counterparts in science and mathematics skills. Clearly, a national education and training crusade is required if these trends are to be reversed and if the human resource−related future of the U.S. electronics industry is to be secured. This imperative is set against a backdrop of crumbling U.S. public school budgets, teacher shortages in science and mathematics, and performance declines in many U.S. communities. The title of the seminal study on the U.S. education system in the 1980s, *A Nation at Risk* , has proved only too prophetic.

Precommercial R&D and U.S.−Style National Industrial Policy

In order to fortify U.S. high−technology competitiveness and to spur investments in nondefense R&D, some U.S. industry and government groups have been calling for vigorous new public−private cooperation and initiatives. In this vein, a panel of the National Academy of Sciences under the chairmanship of Harold Brown, a former Secretary of Defense, called in 1992 for the creation of a Civilian Technology Corporation (CTC)—a quasi−governmental, but private, institution with a one−time $5 billion appropriation—to serve as a clearing−

house for federal investment in precommercial research and development.

Arguing that most current federal R&D programs lack sufficient resources and focus to support technology commercialization over the long term, the National Academy of Sciences (NAS) panel called for a "new federal role to include facilitating, but not directing, civil technology development in precommercial areas and to encourage also the adoption of new technologies by U.S. firms."30 ("Precommercial phase" generally means at the point of discovery, but before venture capitalists are sufficiently motivated by the technology's potential in the commercial marketplace to invest their own funds.)

Urging the government to reassign a portion of its current funding of basic research for this precommercial development purpose (along the lines of the limited targeted outlays for commercial technology projects achieved through the Pentagon's Defense Advanced Research Projects Agency [DARPA]), the CTC would allocate funds to selected companies working in those technology fields through matching grants, direct investments, loans, and loan guarantees, or on a contractual basis. Program expenditures were foreseen at the level of $1 billion per year. Suggested guidelines included cost−sharing, industry participation (leadership) in project initiation and design, openness to foreign firm participation, assessment of the potential for substantial contribution to the U.S. GDP, and a diversified set of R&D objectives. This has engendered strong debate. The proposals have not received sufficient support in terms of proposed enabling legislations.

A task force of the Carnegie Commission of Science, Technology and Government under Admiral Bobby R. Inman, former Director of the National Security Agency, has called on the DARPA to become NARPA, a National Research Projects Agency, to support high−risk technologies of commercial value and to assist the military and other federal agencies as well as the civilian sector.31 This has been countered by proposals to expand the Department of Commerce's totally civilian National Institute of Standards and Technology.

The DARPA−NARPA and CTC−related issues are just the most recent manifestations of the ongoing, but recently transformed national debate on the merits and demerits of U.S. industrial policy as it applies to competitive U.S. high−technology industries.

After years of debate, obvious, if unoriginal core reality seems to have finally come home to U.S. industry and many policymakers of varying political persuasions: in a fiercely competitive world with at best an imperfect international trade regime, "the capture of strategic industries can indeed produce multiple benefits, including high profits, high wages, strategic market niches and cumulative technical learning."32 This is particularly the case with the electronics industry and related information technologies. Bit by bit over the past few years, the United States has begun to rediscover its growth−oriented cooperative government−private sector policies of past years. Important early examples are the nineteenth century's government−backed transcontinental railroads and the network of land grant universities whose research and extension services led to the world's premier agricultural capability. In the current century in an ad hoc industrial policy setting, U.S. government funds have nurtured infant industries, such as aircraft and space, telecommunications, electronics, and biotechnology. Most recently, bridges between anti− and pro−industrial policy adherents have been laid through the establishment of the DOC's National Institute of Standards and Technology (NIST), the Advanced Technology Program (ATP), a new federally−funded technology policy group (the Critical Technologies Institute), and the development of precompetitive technologies by six industry consortia in ceramic fibers, optical electronics, linguistic data processing, parallel computers, and advanced memory chips under the dual−use, shared funding DARPA program where DARPA will leverage significant private sector resources.

A common underlying principle of these programs is that whereas the federal government may sow the seed corn, it is incumbent upon the U.S. private sector to develop commercially viable products and processes. Thus, ultimately and logically, the market—not government—continues to pick the winners and losers. With this hybrid U.S.−style national industrial policy model in mind, a chorus of U.S. electronic industry voices has become increasingly vocal in calling for a collaborative public−private growth policy.

The central theme of current, revised U.S. approaches to industrial policy is to provide a modest amount of federal funding (coupled with appropriate shifts in spending categories of previous years) to bolster and motivate private investors in their pursuit of the next decade's technological winners. A corollary tenet is to resist allowing the degeneration of these funds into protection or death−delayers for the last decade's losers. Of course, the quest is to discover which new technologies will provide massive economy−wide benefits. Many guesses will be wrong, but the re−

cent EC model seems to be attracting increased U.S. policy attention. Under it, the EC sets up projects to spur investment in high−technology ventures, such as computer software, semiconductors, or HDTV, then invites partnerships of businesses and research institutes to bid for grants and to combine their own resources, and artfully combines market and public incentives with private sector partners required to provide half the cost of the investment, thus ensuring responsible use of public funds.

The Reagan and Bush administrations opposed large−scale federal programs. The United States may move cautiously in a new direction under President Clinton. Piecemeal industrial policy through a series of congressional and state initiatives will also continue. Many of the state−level initiatives emulate the highly successful agricultural extension services by providing technical extension agents who travel to assist small factories, many as manufacturing engineers and consultants. There is a campaign in Congress to expand 'these federal and state initiatives by some $500 million per year for civilian technology programs and to establish a nationwide industrial−technology extension program on the agricultural model.

A Final Look at the U.S. Electronics Industry

As the world's technology sectors engage the challenges and opportunities of the final decade of the twentieth century, it is instructive to highlight a few final profile elements of the current U.S. electronics industry, key trends affecting it, and its place in the global technological and market setting.

In the 1990s, the world of technology development and use will be transformed by an accelerated convergence of computers and telecommunications, as "telephones move to the air and computers usurp the television set."33

Due to the rapid developments and application of digital electronics, the lines are blurring between four major industries: computers, consumer electronics, communications, and entertainment. Competitive and functional needs flowing from this technology−induced industry restructuring will accelerate the pace and broaden the scope and players in creative, previously unheard of alliances. Consumers and industrial users, in turn, will receive greatly enhanced performance, new services, and dramatically lower prices.

The dearth of available capital (even in Japan) will push U.S., Asian, and European companies increasingly into joint technology development and manufacturing agreements, particularly in capital−intensive areas such as semiconductor production.

Beyond the cost−sharing and competitiveness−heightening elements of rising globalization of the electronics industry lie twin core corporate realities: (a) increasingly inadequate return on investment in high−cost technology races that no one can profitably win; and (b) obtaining adequate "return on innovation."[34] Cooperation is accordingly often viewed as less expensive than unalloyed competition.

At a time when key subsectors of the U.S. industry are maintaining position, regaining lost ground (for example, the recent resurgence in the semiconductor field), even surging ahead of global rivals, the principal competitor U.S. industry (Japan) has been confronted with a set of severe limits: lower prices, lower profits, declining market share in certain sectors, rising competitiveness of other manufacturers (especially Korea, Taiwan (China), and the People's Republic of China PRC).

With the pronounced downturn in capital spending in Japanese industry, there is an opportunity for U.S. electronics firms willing to invest now to carve out technological leadership positions in a number of market areas.

The explosion of foreign alliances complicates U.S. efforts to forge an effective, national industrial policy for the electronics industry and related high−technology sectors. If U.S. producers are teamed with Japanese, other Asian, or European partners in major financial and technological undertakings, there is a question of whether sufficient resources and energy will be left for U.S. industry−government initiatives. The further question relates to how the sharing and corollary protection of competitive technology data can be handled when U.S. companies are participating in rival development initiatives with foreign partners. This question has never been fully resolved in the instance of several member firms of SEMATECH which take part in a number of similar technology undertakings with foreign companies. It is a critical item of discussion in the EC in their own cooperative efforts.

Regardless of complexities, most observers still believe that foreign and domestic electronics manufacturers have little choice—financially or technically—but to engage in strategic partnerships and alliances. Each alliance will have to be worked out, point−by−point, on its merits and trade−offs.

The increasingly complex dynamics of forces and counterforces within the U.S. electronics sector poses compelling but manageable challenges for

one of the world's most vigorous and vital industries.

Notes

1. The American Electronics Association (AEA).

2. AEA, *1992 State of the Industry Report: Meeting the Challenge of Japan.*

3. Although the term "electronics" has always been difficult to define with precision, especially as new technologies and applications constantly appear, these U.S. DOC statistics concentrate on the industrial segment of the overall industry's products and largely leave out the consumer segment. Thus the DOC numbers focus primarily on the following seven subindustries: business equipment (including photocopiers), computers, electronic components (including semiconductors), instruments (including automatic test equipment), semiconductor manufacturing equipment, software, and telecommunications. These categories are covered by the following SIC codes (Standard Industrial Classification): business equipment−SIC codes 3574, 3579, 38616; computers−SIC 3573; electronic components−SIC 367; instruments−SIC 382; software−SIC 7372; telecommunications equipment−SIC 3661, 36621.

4. "All firms that manufacture electronic components and/or products or systems that require electronic components to perform their intended function; electronic research and development and engineering services companies." *The U.S. Electronics Industries Annual Statistical Report, 1985,* AEA.

5. AEA, *1992 State of the Industry Report.*

6. Bureau of Labor Statistics.

7. See "Manufacturing Offshore is Bad Business," by Constantinos C. Markides and Norman Berg, *Harvard Business Review,* September−October 1988. Also, "ADDS is Bringing A. Lot of It Back Home," *Electronics,* January, 1989.

8. VLSI Research Inc., Report of April 4, 1992.

9. *New York Times,* September 24, 1991, Andrew Pollack.

10. Department of Commerce (DOC).

11. Stockman & Associates, Inc., "The Strategic Partnering Process," 1991.

12. *Perspectives: Success Factors in Critical Technologies,* Computer System Policy Project, Washington, D.C., July 1990.

13. *Fortune,* April 20, 1992.

14. *The Cost of Capital in the United States and Japan,* George Hatsopoulos and Stephen H. Brooks, 1987.

15. Douglas Bernheim and John Shoven of Stanford University estimated that the U.S. electronics industry capital cost disadvantage may have risen to a factor of three since the 1986 Tax Reform Act's repeal of the investmenttax

credit and the raising of capital gains tax rates to those of ordinary income.

16. OECD study quoted in Hatsopoulos and Brooks, p. 14.

17. Data: DRI/McGraw−Hill, see *Business Week* , January 27, 1992.

18. AEA, *1992 State of the Industry Report.*

19. Reid Dennis, as quoted in *Upside Magazine,* November 1991.

20. *New York Times,* March 10, 1992.

21. "Venture Capital Analysis," by Robert Stavers, James Atwell, and Brian Goncher in *Upside Magazine,* November 1991.

22. National Science Board, "Science and Engineering Indicators," February 1992.

23. Organization for Economic Cooperation and Development.

24. *San Jose Mercury News,* May 29, 1992.

25. Evidence of this trend is well documented by the January 1990 agreement between IBM and Siemens to coordinate R&D and production efforts in the 64 megabit DRAM arena where the costs of the new manufacturing line alone are expected to exceed $1 billion.

26. A recent Labor Department projection of job growth through the end of the century indicates that computer programming is expected to be the number one occupation in absolute growth terms. More than 250,000 new jobs are predicted to open between 1988 and the year 2000, a 48 percent increase. If the second largest job growth category, computer systems analysts (a closely related field) is combined, almost 500,000 new jobs will be added to the software−related occupational categories by the year 2000. These dramatic job growth predictions mirror the belief of many that the U.S. software market will reach the $1 trillion level by the year 2000. See story by John Markoff, *New York Times,* May 24, 1990.

27. *Toward a Competitiveness Agenda,* Business Higher Education Forum, Washington, D.C., p. 25.

28. *Toward a Competitiveness Agenda,* Business Higher Education Forum, Washington, D.C., p. 25.

29. Michael Lockerd, Vice President of Texas Instruments, as quoted in the *San Jose Mercury News,* Steve Kaufman, February 9, 1992.

30. "The Government Role in Civilian Technology: Building a New Alliance," National Academy of Sciences, Washington, D.C., March 1992.

31. "Pentagon Wizards of Technology Eye Wider Civilian Role," *New York Times Magazine,* April 19, 1991.

32. Robert Kuttner, "Facing up to Industrial Policy," *The New York Times Magazine,* April 19, 1992.

33. George Gilder, *Wall Street Journal,* July 29, 1992.

34. Phrase of Michael Shrage, *Los Angeles Times* as quoted in the *San Jose Mercury News,* July 20, 1992.

8—
European Electronics: From Crisis to Collaboration

Wayne Sandholtz

The electronics sectors in Europe offer a host of paradoxes. One is that though basic science in Europe is world class, and though European inventors have produced many electronics breakthroughs, European producers are not stellar performers on world markets. Many of the crucial early advances in solid−state physics emerged from Europe, as did the world's first fully digital telecommunications exchange and compact disc technology. Yet U.S. and Japanese firms dominate the major electronics market segments —semiconductors, computers, and consumer electronics—with European companies excelling only in niches here and there. Even Europe's traditional stronghold, telecommunications equipment, has been suffering a loss of market share.

A second paradox, and one that supplies the theme for this chapter, concerns the relationship between governments and the electronics industries. No European government has adhered to a pure *laissez−faire* economic doctrine with respect to the electronics sectors. Even governments with decidedly anti−interventionist economic ideologies (like those of Margaret Thatcher in the United Kingdom and Helmut Kohl in Germany) have been unwilling to leave the fate of the electronics industries entirely to market forces. The prevailing consensus in every capital has been that the electronics complex (including at least semiconductors, computers, and telecommunications) constitutes a strategic sector, one crucial to growth and competitiveness across all economic fronts. The paradox is that even as governments sought to promote national champions in each major branch of electronics, the firms themselves were busy forming partnerships with U.S. and Japanese rivals. National flagship companies commonly depended on foreign sources of technology.

By 1980, the national champion strategies of governments in Europe had failed to propel European electronics firms to the top ranks in international competition. A new dimension in policy then emerged, one crafted at the European level. New programs fostered collaboration on research and development (R&D) across European borders. The European Community (EC) led the way in the mid−1980s by mobilizing support among companies and governments for two large−scale collaborative programs: European Strategic Programme for Research and Development in Information Technologies (ESPRIT) and Research on Advanced Communications in Europe

(RACE). A third joint European R&D program, European Research Cooperation Agency (EUREKA), established outside of EC auspices, also included a strong electronics emphasis. The multiyear budgets for ESPRIT, RACE, and EUREKA total some ECU 14 billion ($17.2 billion).[1]

What is remarkable about the flurry of collaborative European programs is that the electronics sectors, given their commercial and military importance, had always been the exclusive domain of national policy. This chapter explains the sudden burst of European cooperation in terms of two factors: the failure of national champion strategies and policy leadership exercised by the Commission of the European Community (CEC). Politics and electronics have always been intimately linked in Europe; the collaborative programs were the product of political choices and require political analysis.

The first section of the chapter recounts an earlier crisis in European electronics, the "technology gaps" scare of the late 1960s, and the purely unilateral, nationalist policies that emerged in response. The technologies in question were the key elements in the electronics revolution: the integrated circuit and the computer. The chapter also depicts the crisis of the early 1980s, when national champion strategies in the basic electronics industries (semiconductors, computers, and telecommunications) were perceived to have fallen short. The second section provides political analyses of the launching of ESPRIT and RACE. The third section examines measures beyond the two EC programs to strengthen European electronics industries. Finally, the conclusion assesses some of the persisting challenges faced by European electronics industries. Although the collaborative programs launched in the 1980s did not (and could not) bring European electronics industries to parity with U.S. and Japanese rivals, cooperation can nevertheless help to solidify Europe's technology base.

The Technology Gaps Crisis

In the eyes of European political leaders, the electronics sectors were seen as economically strategic by the late 1960s. Governments saw electronics (especially semiconductors and computers) as the key to a new industrial revolution. Economic growth, policymakers believed, would depend in the future on internationally competitive electronics industries. On that score, there were substantial grounds for pessimism.

Beginning in 1966, the Organization for Economic Cooperation and Development (OECD) carried out a series of studies of national differences in several technologically advanced industrial sectors. The resulting reports carried the title *Gaps in Technology*. The reports caught attention in Europe because they concluded that European countries were on the wrong side of the gaps. The OECD analysts declared that the United States was dramatically ahead of Europe in the creation and diffusion of key productivity−enhancing innovations. *Gaps in Technology* included sectoral reports on electronic components and computers. In components, European firms were found to be making only marginal contributions to technological advancement. In computers, 90 percent of all installed machines in the West were of U.S. origin, with IBM accounting for 75 percent of the total.

The American Challenge , a book by Jean−Jacques Servan−Schreiber that also emerged in the late 1960s, reinforced the main conclusions of the *Gaps in Technology* reports, but presented an even more apocalyptic vision of Europe's plight. Servan−Schreiber focused particularly on electronics, which he saw as "the base upon which the next stage of industrial development depends . . . ." He asserted that "if Europe continues to lag behind in electronics it could cease to be included among the advanced areas of civilization within a single generation."[2] The OECD and Servan−Schreiber assessments provoked a technology gaps crisis in European industrial and policymaking circles. However, despite the calls in both studies for increased European cooperation in electronics, the policy response was a series of national−champion strategies, each country seeking to promote its own electronics giants. Because telecommunications differs in important ways from other electronics sectors, it will be discussed separately from semiconductors and computers.

In seeking to establish national electronics champions, European governments employed similar tactics. One common practice was to join several smaller companies into one large one. Government−engineered marriages in the late 1960s produced companies like CII−Honeywell−Bull (the French computer champion, now simply called Bull) and International Computers Limited (ICL) (the U.K. computer flagbearer). From the late 1960s until the early 1980s, French governments sought to create semiconductor champions by trying different combinations of existing firms. The U.K. government in 1978 took the bold step of sponsoring the startup semiconductor company Inmos.

In addition, each country launched government−funded R&D programs for the benefit of domestic firms. The French employed a series of plans to stimulate technological progress. The first *Plan Calcul* began in 1967, the third ended in 1980, with a cumulative total of over FFr 3 billion in R&D subsidies for the computer and semiconductor industries.[3] Two new programs, the *Plan informatisation de la société* and the *Plan circuits intégrés* , added a further FFr 1 billion in the late 1970s.[4] Germany was on a parallel course. From 1967 to 1979, a series of three Electronic Data−Processing Programs spent DM 4.4 billion.[5] German government programs for semiconductor R&D began in 1974; by 1983 subsidies in this area totaled DM 800 million.[6] The U.K. government provided R&D grants to the computer industry beginning in the mid−1960s, and established three initiatives in the late 1970s to support semiconductor research and applications (the Electronic Component Industry Scheme, the Microprocessor Applications Project (MAP), and the Microelectronics Industry Support Plan MISP)). Each government further favored its national champions with public procurement contracts.

The telecommunications sector has become a major user and developer of advanced electronic technologies. With the advent of the digital switch in the mid−1970s, telecommunications exchanges started to resemble large computers in important ways—not least in their massive reliance on sophisticated integrated circuits. As computers have taken over network management, and as data communications have increased dramatically as a share of total telecommunications traffic, the information and communications technologies are gradually becoming one interconnected whole.

The telecommunications equipment industries have traditionally been nurtured at the national level through close ties to the public telecommunications authorities, the ministries of post, telephones, and telegraph (PTTs). In each country, the PTT held a monopoly on the ownership and management of networks, on the provision of services, and on the supply of most kinds of terminal equipment (telephone handsets, modems, private branch exchanges, and so on). Since the PTT was virtually the sole buyer of telecommunications materials, producers of telecommunications equipment came under the tutelage of their PTT. The telecommunications offices became tools of industrial policy.

Consolidation of the network equipment industry was in some cases supervised by the state. For instance, Thomson Telecommunications was the product of a merger arranged by the French PTT, the *Direction Générale des Télécommunications* (DGT). The government itself (over DGT objections) directed the 1983 merger of Thomson Telecommunications with the telecommunications division of CGE, forming Alcatel. In the United Kingdom, the government pressured GEC to take over the smaller AEI, and the British Post Office (BPO) gradually reduced its "ring" of network equipment suppliers from five companies to three in 1969. Equipment monopolies even extended to the devices that customers could attach to the network. The BPO had the power to specify which private branch exchanges and modems could be used, and retained a monopoly on the installation and maintenance of such devices.[7] Similarly, the Bundespost had the sole right to authorize sales of equipment to users, and in the mid−1980s still held onto its monopoly on provision of the first handset and of all modems.[8] The national champions in telecommunications equipment worked closely with national PTTs to prepare technical standards, which then became a barrier to foreign suppliers working to different standards set in collaboration with their own PTTs. Finally, the PTTs worked closely with their national champions to develop new generations of equipment. For instance, the research arm of the DGT in France collaborated with CGE to produce the world's first digital switch in the mid−1970s.

Each national government utilized an array of policies on behalf of its own electronics producers: orchestrated mergers, national technical standards, public procurement, R&D grants, even outright subsidies. None of the national−champion strategies achieved its objective. In fact, by 1980 European electronics producers were competitive only in niche markets, such as specialty integrated circuits. The share of European firms in world semiconductor markets fell from 16 percent in 1978 to 12 percent in 1983; by 1988 it was down to 10 percent.9 From 1977 to 1981, the portion of the European semiconductor market accounted for by European companies declined from 33 to 30 percent.10 Europe's performance in integrated circuits (the most important segment of the semiconductor market) was even worse, with a share of world production in 1982 of less than 6 percent.11 By the mid−1970s there was not a single European maker of commodity integrated circuits (as opposed to custom or semi−custom chips), and by the early 1980s the integrated circuit divisions of Europe's electronics giants were all operating in the red.

In computers, European producers were faring no better. For instance, in 1983 Siemens was the only European manufacturer in the world's top 10 data processing companies.12 In the European market, IBM was number one, with data processing revenues more than seven times greater than those of the second−place company, Bull. The combined share of 13 U.S. firms in the European computer market was 81 percent.13 On top of that, all the major European companies relied on technologies from their U.S. or Japanese competitors: Siemens manufactured mainframes under license from Fujitsu, and ICL's microcomputers were Sun work stations.

Telecommunications equipment had been a European stronghold. But even in this sector there were signs of trouble by the early 1980s. The EC's trade surplus in telecommunications equipment in 1985 registered its third consecutive year of contraction. With both the United States and Japan, the EC trade deficit in telecommunications equipment was growing, suggesting that Europe was weak in the most advanced segments of the market.14 Whereas the European share of world telecommunications equipment exports in 1983 had been declining by 1 percent per year for a decade, the Japanese share had been rising at a comparable rate.

Not surprisingly, a sense of crisis started to mount as European industry and policy leaders

surveyed the situation in electronics in the early 1980s. U.S. and Japanese electronics firms seemed to be leaving European companies behind. This was not just a problem for electronics, because the electronics industries were seen as increasingly crucial to industrial competitiveness in general, and thus to economic growth and employment. The feeling of alarm and much of the rhetoric echoed the technology gaps scare of the late 1960s. In the early 1980s, it was clear that the national champion strategies had failed to transform European electronics giants into world−class competitors. Many leaders—at the EC, in industry, and in national governments—concluded that continued unilateral, nationalist electronics strategies would not suffice. Thus the policy response in the early 1980s acquired an entirely new dimension: cooperation at the European level.

Adaptation and Cooperation

The argument in this section rests on the premise that policymakers can engage in adaptive learning. Whereas policy change is for the most part marginal and incremental, dramatic failures or breakdowns—crises—produce far−reaching reassessments and policy shifts. A clear failure of policy to achieve its major objectives triggers an adaptive process in which decision makers search for new approaches.15 The obvious failure of 15 years of national champion strategies to remedy Europe's deficiencies in electronics provoked a thorough rethinking of policy, as political leaders sought new policy avenues.

Still, European−level cooperation was not the automatic outcome of this adaptive process. There were alternatives. Governments could have decided that revamped unilateral, nationalist policies were the answer, that the failures stemmed from having chosen the wrong kind of national champion strategy. Or, governments could have elected to encourage alliances with U.S. or Japanese firms. Collective action always requires the presence of a leader to mobilize participants and organize the cooperative effort. In European electronics, the CEC played the leadership role. In this section, evidence to show that European governments were in a process of policy adaptation in the early 1980s is first examined. Then the emergence of the collaborative programs ESPRIT and RACE is analyzed.

Policy Adaptation

In each of the major European countries as the 1980s began, and in some of the smaller ones, policymakers were reassessing previous strategies in electronics and searching for new ones. They convened special panels to study electronics policies and recommend new directions. Though each country devised new programs for electronics, they simultaneously turned to R&D policy collaboration in the EC. For instance, the government of François Mitterrand, elected in 1981, was determined to turn around a trade deficit in electronics goods that doubled in 1982. The first step was to set up a *Mission filière électronique* to review the industries and French policy. The Farnoux Report (named after the head of the commission, Abel Farnoux) stated, "If France is to maintain its independence, master the new communications systems and put the crisis behind it, it is imperative for the country to master the key activities of the electronics sector."16 On the basis of the Farnoux Report, the government launched the program for the *filière électronique*, which meant a complete overhaul of French electronics policies. Yet within a year, the Mitterrand government found itself financially strapped and unable to implement the ambitious electronics plan. In the fall of 1983, the government began to speak out in favor of technological cooperation at the European level especially in electronics. At the same time, Laurent Fabius, then Minister for Industry and Research, declared, "Meeting the challenge of electronics and information technologies is the number one priority in industrial policy for the country."17 Thus France retained its commitment to promoting electronics, but abandoned the purely unilateral route to doing so, and turned toward European cooperation.

In Germany, the government of Helmut Kohl was likewise looking for new policies in electronics. The federal research and technology ministry (Bundes Ministerium Fuer Forschung und Technologie (BMFT)), was studying the German electronics industries and putting together a new policy. The *Informationstechnik* program, announced in 1984, aimed to reverse the country's sagging fortunes in electronics. Research minister Heinz Riesenhuber declared that in order to meet the challenge of competitiveness in world markets, "the government has approved the comprehensive plan to support microelectronics, information and communications technology."18 At the same time, elements within the German government—especially foreign minister Hans−Dietrich Genscher and the BMFT—were becoming solid supporters of European collaboration in electronics. Indeed, the German government agreed in 1984 to contribute DM 300 million to a binational microelectronics project called Mega, involving Siemens with Philips of the Netherlands.

The government of Margaret Thatcher in the United Kingdom was divided between two impulses. On the one hand, the government sold off its shares in U.K. electronics firms like Inmos and ICL. On the other hand, it enacted new electronics support policies. A special committee, bearing the name of its chairman John Alvey, was convened to study the U.K. electronics industries. The Alvey Report proposed a major, government−funded program to sponsor cooperative R&D. The budget for the resulting Alvey Programme was the largest for a civil R&D program ever in the United Kingdom.19 Interestingly, the Alvey Programme leadership coordinated its efforts with the ESPRIT program then emerging in the EC. This was possible because the first Alvey director, Brian Oakley, was also one of the key U.K. participants in the planning for ESPRIT.

Italy, the Netherlands, and Belgium also undertook new efforts in the early 1980s to promote their electronics industries. In short, European governments of all stripes were reassessing past electronics policies and searching for new approaches. The evidence of this process of adaptation is the series of special commissions established to review electronics policies, and the new programs that resulted. However, the most significant feature of the adaptation that occurred in the early 1980s was the emergence of cooperative R&D programs at the European level. The first of these was ESPRIT.

Esprit

In the late 1970s, a group of officials at the CEC became convinced that only with a collaborative approach could European electronics industries compete with U.S. and Japanese rivals. A new arrival at the CEC, Etienne Davignon, converted the working group into the Information Technologies Task Force (ITTF) and vigorously promoted its efforts. Indeed, Davignon had taken his post as commissioner for industry in 1979 possessed of a strong conviction that electronics was crucial for the competitiveness of European industries. In September of that year, he proposed that the electronics industry, governments, and the EC jointly devise a strategy. Within months, Davignon took the step that proved decisive in launching ESPRIT: he invited executives from the EC's 10 largest electronics companies to meet with him. The meeting took place in February 1980. On the agenda was the CEC's idea of an EC−level electronics policy. The industry representatives agreed with Davignon's diagnosis of the problems, arid responded favorably to the suggestion of an EC Policy.[20]

In late 1981, Davignon brought together the directors of the EC's 12 largest electronics companies for a series of "roundtable" discussions.[21] He told them that if they wanted to cooperate with each other, he would come up with funds for a substantial EC program. The Roundtable executives tentatively agreed, and continued to meet, forming a steering committee to work with the CEC on the outlines of a strategy. They decided on five major areas that a collaborative R&D program should cover: advanced microelectronics, advanced computing, software technologies, office automation, and computer−integrated manufacturing. By the spring of 1982, the Roundtable companies had in place five expert panels to work out the details of a work plan. The technical panels expanded to include technologists from companies other than the Roundtable 12, from universities, and from research laboratories.

In August 1982 the CEC proposed that a pilot phase, with a limited number of projects, begin in January 1983 with ECU 10−12 million in EC funding. The program would be named ESPRIT, the European Strategic Programme for Research and Development in Information Technology. The CEC argued that the electronics technologies were crucial to the competitiveness of all European industries, and that a joint program was needed to stay in the electronics race with the United States and Japan. The technological needs were so great that "no one company or country can tackle [them] alone."[22] The CEC proposed that the R&D supported by ESPRIT aim at "precompetitive technology," which was eventually defined as technology that is 5 to 10 years from commercialization. The Council of Ministers gave formal approval to the pilot phase in December 1982, with EC funding of ECU 11.5 million.[23] In response to its call for proposals, the CEC received over 200 submissions, representing some 600 companies and research institutes. With the help of a senior executive committee that included national officials, the CEC selected 38 projects to receive pilot phase funding.

As the pilot phase progressed, it won high marks from both industry and national governments. This broad approval eased the way for the CEC's proposal for a full−scale program. The CEC called for launching the first of two five−year ESPRIT phases. The budget for the first phase would be ECU 1.5 billion, half coming from the EC and half from participating companies. The ground rules would be the same as for the pilot phase: projects had to address specific parts of the ESPRIT work plan, and each project had to include organizations from at least two EC countries. One important key to winning approval from national governments was the enthusiastic support of industry. In particular, the 12 Roundtable companies carried weight with their home governments, since they were the national champions that each state had nurtured. The Roundtable companies had been involved in designing ESPRIT from the beginning and lobbied their governments to support it. Business executives and national officials who were interviewed stressed that the Roundtable companies were crucial to winning approval for the program.

By the summer of 1983, the 10 EC member governments largely agreed on the structure and goals of ESPRIT. But a dispute over EC finances delayed final approval. In the meantime, important compromises were worked out. For instance, 25 percent of the ESPRIT budget was to be reserved for small−scale projects, a provision intended to help smaller companies (and smaller countries) to participate. The budget impasse was broken, and ESPRIT won formal Council approval in February 1984. The first call for proposals attracted some 441 submissions.

In fact, the response to ESPRIT Phase I was so enthusiastic that the funds allocated for five years were fully allocated in three. The CEC thus moved forward its proposed Phase II, to begin in 1987. The Roundtable companies called for tripling the size of the program, with a proposed EC budget for ESPRIT H of ECU 2.2 billion. ESPRIT II would include a small number of technology−integration projects (TIPs) that would be large scale and focused on practical applications of the technologies. The five technology areas in ESPRIT I were collapsed into three (microelectronics, information processing systems, and applications systems).

The second phase, like the first before it, became mired in larger budget controversies. This time the dispute was over the size of the EC's Framework Programme, the comprehensive umbrella for all EC technology or R&D efforts. Ironically, even Germany and the United Kingdom—the two countries most adamant about reducing the budget for the Framework Programme—supported ESPRIT II. In fact, support for ESPRIT was virtually unanimous. Nevertheless, ESPRIT was held in limbo as the member states bargained over the larger research budget. This logjam broke in the summer of 1987. The EC contribution was ECU 1.6 billion, smaller than originally proposed, but more than twice the budget of the first phase. By this time, the ITTF that produced the original ESPRIT proposals had acquired a more permanent institutional status in Brussels, becoming Directorate General XIII for Telecommunications, Information Industries, and Innovation.

By the time the Council formally approved ESPRIT II in April 1988, the CEC already had in hand over 1,000 project proposals. As of mid−1991, some 500 research projects had been initiated under the aegis of ESPRIT. They involved over 6,000 scientists, engineers, and technologists. ESPRIT projects have addressed a wide spectrum of technologies. The microelectronics section has sponsored, for example, R&D on computer−aided design tools for integrated circuits, submicron lithography equipment, high−density chips, high−speed silicon circuits, compound semiconductors, flat−panel displays, and opto−electronic components. Other projects address parallel computing, artificial intelligence systems, portable software engineering tools, and computer vision. Applications projects focus on multimedia work stations, computer−aided engineering systems, and advanced robotics and automated production systems.

A 1989 review of ESPRIT I found that 90 percent of the participants responding to the evaluators' survey thought that their collaborative projects had worked "well" or "adequately." The most commonly cited benefits from ESPRIT projects were "enhanced know−how" (70 percent of respondents), "more ambitious R&D goals" (60 percent), "new products" (47 percent), and "improved development techniques" (45 percent).24 United Kingdom, French, and German executives from Roundtable companies expressed strong satisfaction with ESPRIT.25 They emphasized two valuable gains from ESPRIT: first, a new sense of self−confidence and community in the electronics industries, and second, access to more R&D results than would be possible with just their own personnel and resources.

In July 1991 the Council approved what Jean−Marie Cadiou, director of ESPRIT, called the "next phase of ESPRIT."26 The budget for the latest phase is nearly ECU 500 million. The new "specific program" will focus its spending on a smaller number of large−scale projects. The targeted projects are to integrate diverse technologies to pursue more practical aims (presumably meaning that they should be closer to commercial application than previous ESPRIT projects). Users of electronics technologies (as opposed to just producers) have been involved in defining the new projects.

ESPRIT was a breakthrough in European electronics policy. It ended decades of purely unilateral, national champion strategies. The perceived success of ESPRIT generated a new sense of self−confidence and support for

EC−level technological collaboration. The enthusiasm surrounding ESPRIT prepared the way for further

cooperative efforts in electronics. The next step was RACE.

Race

Telecommunications in the early 1980s was in a state of technological and regulatory flux worldwide. Digital electronics had revolutionized telecommunications equipment, making possible networks of computers and computerized networks. New transmission modes—satellites, microwave, and fiber optics—greatly expanded the capacity and versatility of telecommunications systems. The new technologies made possible a proliferation of new services, from large−scale data communications to video conferencing. Emerging integrated networks will simultaneously carry signals of all varieties: data, text, sound, and high−quality images (eventually including high−definition television [HDTV]).

In the early 1980s, telecommunications authorities were coming under pressure to permit more competition in the provision of networks, services, and equipment. Historically, the PITs had exercised monopoly control over all aspects of telecommunications. But with the explosion of new technologies and services, both suppliers and users of telecommunications equipment and services began to urge liberalization. The United States took the lead in deregulation with the breakup of AT&T in 1982. Japan introduced competition in some aspects of telecommunications and undertook ambitious plans for a nationwide fiber optic network. In Europe, however, the United Kingdom was the only country to pursue significant liberalization as of the early 1980s.27 Though there have been significant steps toward coordinating the liberalization of European telecommunications, this chapter examines the electronics industries in Europe and therefore focuses on the emergence of collaborative R&D in the telecommunications sector.28

The EC trade surplus in telecommunications equipment began declining in the early 1980s. In particular, the EC had registered a trade deficit in the sector with both the United States and Japan. The deficit with the United States grew by 25 percent to ECU 657 million in 1985; the deficit with Japan increased by 61 percent to ECU 582 million.29 Some Europeans—in industry, national governments, and the EC—began to worry that the last bastion of European strength in electronics, the telecommunications sector, was beginning to crumble under the pressures of international competition.

As with microelectronics and computers, the impetus for European collaboration in telecommunications R&D came from the CEC.30 Etienne Davignon and his colleagues on the ITTF considered telecommunications to be a crucial part of the broad electronics sector, which they called "telematics." Thus Davignon already in 1979 was meeting with the heads of the EC's PTTs and advocating a common approach to modernization and harmonization in telecommunications.31 In addition, the ITTF had proposed to the Council an EC response to the challenges of the new information and communication technologies. The Council requested specific proposals in microelectronics and telecommunications, which the CEC submitted in July 1980. The telecommunications paper called for a harmonized Europe−wide telecommunications network and for opening of the national markets for telecommunications equipment.32 More specific proposals followed, but the Council did not act on them until 1984.

In the meantime, of course, the CEC was busy putting together ESPRIT. It made tactical sense for the CEC to focus on microelectronics and computers first, and to follow with telecommunications. To begin with, ESPRIT would cover many of the basic semiconductor technologies needed for telecommunications systems. A telecommunications program could therefore exploit and apply some of the results of ESPRIT. Equally important, starting a program in telecommunications would be far more challenging politically because the sector was dominated by the entrenched and monopolistic PTTs. A successful ESPRIT program would make it easier to proceed in telecommunications because it would show that the CEC was capable of running a significant high−technology program.

In December 1982 the Council approved the ESPRIT pilot phase, and in February 1984, it formally endorsed ESPRIT I. During this Period, the CEC was starting to put in place some of the pieces of a telecommunications strategy. In September 1983 the CEC proposed to the Council six point or "lines of action" in telecommunications.33 Three of the six points (joint planning for future networks, cooperation on R&D, and common standards) would take shape in the RACE program. At the CEC's suggestion, the Council asked the CEC to organize a committee in which ministers of industry and the telecommunications industries would be represented. The result was the Senior Officials Group for Telecommunications (SOGT). The SOGT met under CEC leadership and used as its basis for discussion the six lines of action outlined by the CEC.

By May 1984, the SOGT and the CEC had agreed on the elements of an EC telecommunications program. The CEC forwarded the plan to the Council, arguing that "the capacity to meet these

challenges [posed by the United States and Japan], and to cope in a timely manner with the opportunities born out of the development of telecommunications, is outside the capability of national operators on their own."34 The program would in−dude creation of an EC telecommunications market through common standards and open procurement, planning future networks, technology development, and aid for telecommunications development in developing regions. The CEC promised to have a program for R&D cooperation on the table by the end of the year.35

In designing the R&D program, the CEC began with the same 12 Roundtable companies with which it had worked on ESPRIT. The large electronics firms were all involved in telecommunications equipment markets in addition to semiconductors and computers. The companies were interested in R&D cooperation because the new generation of digital switches was so costly to develop (up to $1.5 billion). The European firms were further pressured by the fragmentation of the European telecommunications market; none of the EC member states had a home market large enough to support a domestic telecommunications supplier given the scale of investment required. Representatives of the ITTF presented to the leaders of the Roundtable companies the CEC's assessment of the problems facing the industry. They proposed that industry help devise a collaborative R&D program aimed at broadband communications. The companies agreed, and during the summer of 1984, 80 experts from industry met twice weekly to determine which R&D activities should be included in an EC program. The result was a detailed work plan for RACE: R&D in advanced communications technologies in Europe. The de−dared objective was "Community−wide introduction of Integrated Broadband Communication (IBC) by 1995."

RACE would include joint planning of the future broadband (fiber optic) network, as well as cooperative R&D on hardware and software. As with ESPRIT, the R&D would be precompetitive. The CEC (with help from industry experts) would select projects for funding from among those proposed by groups of EC companies, laboratories, and universities representing at least two countries. The EC and participating firms would each put up half the funding for the program. A RACE Definition Phase was passed by the Council in July 1985, with an EC contribution of ECU 20 million. Out of 80 proposals received for the Definition Phase, only 30 could be funded. By the time it concluded at the end of 1986, the RACE Definition Phase was winning strong expressions of approval and support from participating organizations. For instance, over 90 percent of participants responding to a survey replied affirmatively to the question, "Has working directly together with your colleagues from other countries been of benefit and do you consider this to be important to the strengthening of Europe's posture?"36

Before the Definition Phase was completed, in October 1986, the CEC proposed to the Council a RACE Main Phase. The Main Phase would last five years and have an EC budget of ECU 800 million, making for a total budget of ECU 1.6 billion. Like ESPRIT II, the RACE Main Phase became a hostage to the dispute over the larger R&D Framework Programme. Final approval for RACE was thus delayed—even though the program enjoyed strong support from industry and governments.37 Formal ratification of RACE came in December 1987, with a budget of ECU 1.1 billion (haft coming from the EC), a reduction from the CEC's original proposal.

RACE consists of three broad tasks: (a) the definition of a reference model for integrated broadband communications, including functional specifications; (b) collaborative R&D on essential technologies for IBC equipment and services; and (c) development of means to test emerging equipment and systems, including full−scale pilot applications. The R&D portion has included projects covering integrated circuits, opto−electronics, broadband switching technology, flat−panel displays, and HDTV, among others. The pilot projects are addressing specific real−world applications, in banking and finance, publishing, manufacturing, retail and distribution, medical records, transportation, and services for disabled persons. About 300 organizations participate in 92 RACE projects.

Finally, in mid−1991, the Council approved a follow−on telecommunications program, or "specific programme of research and technological development in the field of communications technologies." For the period 1990−94, the specific program has a budget of ECU 489 million. It will build on projects begun in RACE and in addition sponsor work on intelligent broadband systems, mobile communications, image and data communications, and information security technologies.

Beyond ESPRIT and RACE

The two major EC programs triggered a number of other efforts aimed at strengthening the European electronics industries. Some of these related activities focus on R&D, but others address common standards and opening up the internal EC electronics markets.

The EUREKA program is the largest and broadest of the R&D−oriented endeavors. EUREKA was concocted as a European response to the U.S. Stra−

tegic Defense Initiative (SDI).[38] The motive was not to develop a missile defense system like "Star Wars." Rather, European officials worried that SDI research would give U.S. companies an advantage in high−technology *commercial* industries, and that SDI funding would attract European scientists and engineers. To be sure, SDI covered technologies with extensive industrial potential, especially in computers, software, and communications. The Mitterrand government in France thus proposed in the spring of 1985 a pan−European R&D effort that would parallel SDI, but be dedicated entirely to civilian applications. By the summer, 17 countries had agreed to launch EUREKA.

The new program differed from ESPRIT and RACE in crucial respects. First, it took shape outside the EC. Second, EUREKA was explicitly aimed not at precompetitive R&D but at technologies that would have commercial potential in the short term. Third, EUREKA had no centralized funding of its own. Rather, companies wishing to participate in a EUREKA project had to win approval as well as funding (if any) from their home government. Finally, EUREKA had no well−defined technological agenda. The content of the program emerged as projects were added to the list, eventually filling out nine categories: information technologies, telecommunications, biotechnologies, robotics and automation, the environment, new materials, transport, energy, and lasers. The electronics sectors (information technology and telecommunications) have constituted the largest group with nearly 30 percent of the total number of projects. As of mid−1991, there were over 500 EUREKA projects worth a total of more than ECU 8 billion and involving some 3,000 organizations. Among the highest−profile EUREKA projects have been those for a computerized road traffic system, HDTV (coordinated with parallel ESPRIT and RACE projects), and Joint European Semiconductor Silicon (JESSI).

JESSI was to be a flagship program to develop next generation integrated circuit design and manufacturing technologies. It had a troubled beginning, as Siemens and Philips clashed with SGS−Thomson over the latter's role in the program. Eventually JESSI became an umbrella for some 70 microelectronics projects and received partial funding from the EC. However, the program has been troubled by disagreements and uncertainty. Its 1992 budget was cut by about one quarter to ECU 400 million when both the EC and participating companies reduced their contributions.39

Several new European programs have been created as a direct result of ESPRIT. On the R&D side, and as a result of contacts formed in the planning of ESPRIT, Bull, ICL, and Siemens established a joint research center on advanced computing. The European Computer Research Center was launched in January 1984 and has its own laboratory outside Munich. Other ESPRIT spinoffs have focused on standards, in large part as an effort to break the hold of IBM's proprietary standards. The 12 electronics firms that began meeting in the CEC's Roundtable shortly thereafter formed a group called Standards Promotion and Application Group (SPAG) to open standards. SPAG has urged conformance to Open Systems Interconnection (OSI), a family of standards designed to allow computers of different makes to communicate and swap information and files. SPAG later became a jointly owned company that originated a number of European standards proposals and also provided test services to verify compliance with European standards. A separate group calling itself X−Open formed in 1985 to encourage the use of the Unix operating system. X−Open started with six European computer manufacturers but has since expanded to include several U.S. firms. OSI and Unix have been spreading in Europe. Thus national markets formerly separated by distinct standards are being melded into a larger regional market. One indication that the standards are having the desired effect is that IBM in the mid−1980s announced that in Europe it would offer equipment conforming to OSI standards and running on Unix.

On the telecommunications side, RACE was the CEC's wedge for breaking open the PTT monopolies.40 Under CEC leadership, the EC has a new institutional framework for creating common telecommunications standards. At its heart is a new organization created at CEC urging, the European Telecommunications Standards Institute (ETSI). ETSI works in conjunction with the CEC and with existing European standards bodies (European standards committee [CEN] and European committee for electrotechnical standardization [CENELEC]), to formulate common standards for telecommunications networks, equipment, and services. Again, the effect is to begin creating a large regional market out of fragmented national ones.

Equally significant, the CEC has taken dramatic steps to open competition in telecommunications markets. The first step was to issue a directive in April 1988 requiring that the supply of terminal equipment (facsimile machines, modems, mobile telephones, and satellite dishes—everything except the first telephone handset) be open to competition. Some member countries challenged the CEC's unilateral approach, but the European Court of Justice upheld the directive in a March 1991 ruling. The Court decision has solidified the position of a second CEC directive aimed at ending monopolies

that provide telecommunications services (except voice telephony). The services directive of June 1990, combined with an EC agreement on Open Network Provision, means that service providers and users will have access to the telecommunications network anywhere in the EC. Finally, the CEC initiated efforts in 1990 to open the procurement markets, that is, to allow competition in the awarding of contracts for network equipment (transmission and switching) by telecommunications authorities.

Persisting Challenges

The most striking feature of European efforts to promote the competitiveness of the electronics industries is the addition of collaboration to what had previously been a domain of purely unilateral, nationalist strategies. As is argued in this chapter, the move to collaboration was the result of the clearly perceived failure of national champion strategies combined with effective political leadership from the CEC. Cooperation has affected R&D as well as standards and the opening of the internal European electronics markets. The creation of EC−scale markets is extremely important, as the national markets—even in large countries like Germany and France—are simply not big enough to support internationally viable electronics firms. Microelectronics, computer, and telecommunications producers need a larger home market than any one country can provide. Of course, the 1992 program added a new impetus to the efforts to create a true EC market.

However, even an EC market in advanced electronics is almost certainly too small to support all of the electronics champions that national governments have nurtured through the years. Indeed, a process of consolidation in the electronics industries began in the early 1980s and continues. In semiconductors, the leading French producer, Thomson, merged with the Italian champion SGS to form SGS−Thomson. According to a Thomson executive who was interviewed, the merger came about in large part as a result of contacts formed in ESPRIT. SGS−Thomson later bought the U.K. producer Inmos. The computer industry has also been consolidating. Siemens acquired its smaller German competitor Nixdorf in 1990. Olivetti has reportedly been searching for a suitable partner.41 The telecommunications equipment industry has been also seen a number of important mergers. Two U.K. producers, GEC and Plessey, combined their telecommunications divisions in 1988. Ericsson of Sweden purchased a controlling stake in the French telecommunications producer CGCT. The biggest merger was that joining Alcatel and ITT in 1987, which created the world's largest manufacturer of telecommunications equipment. In March 1992, Alcatel increased its 56 percent share of the partnership by buying out ITT's 30 percent.

Though consolidation was (and probably still is) unavoidable, mergers and partnerships with non−European electronics companies raise thorny issues. For instance, when ICL of the United Kingdom was purchased by Fujitsu, it was kicked out of the joint computer research program with Bull and Siemens. Ironically, Siemens' top−line mainframes had been manufactured under license from Fujitsu since 1978. Siemens also has a semiconductor agreement with Hitachi, and in 1991 linked up with IBM to develop jointly a 64−megabit memory chip. Indeed, virtually all European electronics firms have links to non−European companies. The Japanese firm NEC has a 4.7 percent stake in Bull, which distributes NEC mainframes in Europe. Bull recently bought the laptop computer business of Zenith, and in early 1992 IBM took a 5.7 percent stake in Bull. The partnership with IBM (which also involves SGS−Thomson and Apple Computers) will cover research, technology sharing, and marketing. The U.S. firm Digital Equipment took over the minicomputer business of Philips in 1991.

Dependence on foreign sources of technology underscores Europe's continuing weakness in key technologies, especially integrated circuits. Despite the array of programs developed to promote electronics—R&D support, common standards, market opening within Europe, and trade protection—at both the national and EC levels, European firms remain fundamentally behind. For instance, in 4−megabit memory chips, the European share of the world market is less than 2 percent.42 For semiconductors overall, Japanese firms held 45 percent of the world market in 1991, U.S. firms 40 percent, and European firms about 10 percent.43 The situation is no better in computers. Of the world's top 10 companies, 3 are European: Siemens−Nixdorf, Olivetti, and Bull, at the eighth, ninth, and tenth spots, respectively. Their combined share of the European market was only 11.6 percent. The European share of the world computer market is about 12 percent. Furthermore, each of the three major European computer firms has been losing money.44 In telecommunications equipment, the EC trade balance continues to decline, from a surplus of ECU 1.5 billion in 1985 to one of less than ECU 100 million in 1989. Over the same period, the EC's

trade deficit with Japan in telecommunications widened from ECU 536 million to ECU 1.17 billion.45

The enduring dilemma for European electronics is the following. Governments, companies, and the EC all want to strengthen the electronics industries so that they can compete better with U.S. and Japanese multinationals. But at the same time, European firms depend on U.S. and Japanese rivals for key technologies or components, including microprocessor and memory chips. Certainly European producers have been able to purchase the components they need. But the risk, frequently cited as a real occurrence, is that non−European suppliers tend to make available second−best technologies, reserving the top−of−the−line product for their own equipment−making divisions or for traditional customers at home. Another complaint in Europe has been that during periods of shortage, foreign competitors receive preferential access to tight supplies.

Does reviving Europe's electronics industries imply a need to cut the ties to U.S. and Japanese companies? Not at all. In fact, European firms, like Japanese and U.S. ones, will continue to need cross−national alliances and partnerships. Technological change is so rapid and costly, and markets so international, that no region can afford to isolate itself from the others. But do the ongoing links between European firms and U.S. or Japanese partners make pointless the efforts to strengthen European electronics industries? Again the answer should be no. If European producers are to make alliances as something other than subcontractors or distributors, they need to have something to offer technologically. Furthermore, if European industries are to be capable of absorbing and using the best technologies from abroad, they cannot be too far behind the leaders. In other words, Europe must continue to seek improvements in its own technology base.

Though the collaborative programs initiated in the 1980s have not cured Europe's electronics ills, they are important parts of the treatment. By letting scarce R&D resources (funds and personnel) go farther, and by encouraging the spread of technologies and know−how among networks of European companies, cooperative R&D will strengthen Europe's technology base in electronics. The opening of formerly fragmented national markets will give European electronics houses a larger and stronger base on which to build. Indeed, it is only because of the cooperative initiatives of the 1980s that it makes sense to speak of a "European" electronics industry at all.

Notes

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16. Quoted in OECD, *Innovation Policy: France* (Paris, 1986), p. 218.

17. "M. Mitterand: la France proposera un plan européen de haute technologie en 1984," *Le Monde* , September 27, 1983, p. 44.

18. Quoted in Thomas R. Howell, William A. Noellert, Janet H. MacLaughlin, and Alan W. Wolff, *The Microelectronics Race* (Boulder, Colo.: Westview Press, 1988), p. 174.

19. See Alan Cane, "Britain Enters the Great Race," *Financial Times*, May 9, 1983, p. 12.

20. For a more complete account of the story of ESPRIT, see Wayne Sandholtz, *High−Tech Europe: The Politics of International Cooperation* (Berkeley: University of California Press, 1991), Chapter 7.

21. The 12 were Bull Thomson, and CGE from France; Siemens, Nixdorf, and AEG from Germany; GEC, ICL, and Plessey from the United Kingdom; Olivetti and STET from Italy; and Philips from the Netherlands. These companies became known as the Roundtable companies.

22. CEC, *Communication from the Commission to the Council: On Laying the Foundations for a European Strategic Programme of Research and Development in Information Technology: The Pilot Phase* COM (82) 486 Final/2 (Brussels, 1982), pp. 6 and 16.

23. In the Council of Ministers, each country is represented by the cabinet minister whose portfolio covers the issue under discussion. For ESPRIT, the Council included ministers of research and technology. For agricultural questions, the Council would consist of farm ministers. All EC legislation must be approved by the Council.

24. ESPRIT Review Board, *The Review of ESPRIT: 1984 —1988* (Brussels, 1989).

25. The author's interviews with executives from Roundtable companies.

26. CEC, *ESPRIT: Progress and Results, 1990/91* (Brussels, 1991), p. 1. The formal title of the new program is "Specific Programme of Research and Technological Development in the Field of Information Technology."

27. For accounts of the worldwide process of liberalization in this period, see Michael G. Borrus et al., *Telecommunications Development in Comparative Perspective: The New Telecommunications in Europe, Japan, and the U.S.* , Working Paper No. 14 (Berkeley: Berkeley Roundtable on the International Economy, 1985); Jeffrey A. Hart, "The Politics of Global Competition in the Telecommunications Industry," *Information Society* 5, pp. 169−201; Jill Hills, *Deregulating Telecoms: Competition and Control in the United States, Japan, and Britain* (London: Frances Pinter, 1986); Godefroy Dang Nguyen, "Telecommunications: A Challenge to the Old Order," in Margaret Sharp, ed., *Europe and the New Technologies* (Ithaca, N.Y.: Cornell University Press, 1986), pp. 87−133; OECD, *Telecommunications: Pressures and Policies for Change* (Paris, 1983).

28. For a political analysis of telecommunications reform at the EC level, see Wayne Sandholtz, "Institutions and Collective Action: The New Telecommunications in Europe," *World Politics* , forthcoming.

29. CEC, *Towards a Dynamic European Economy*, p. 158.

30. For a more detailed account of RACE, see Sandholtz, *High−Tech Europe* , Chapter 8.

31. *Agence Europe* , December 29, 1979, p. 9.

32. *Agence Europe* , July 18, 1980, p. 6.

33. CEC, *Communication from the Commission to the Council on Telecommunications: Lines of Action* , COM (83) 573 final, pp. 8−13.

34. CEC, *Communication from the Commission to the Council on Telecommunications* , COM (84) 277 final, pp. 10.

35. CEC, *Communication from the Commission to the Council on Telecommunications* , COM (84) 277 final, pp. 14−22.

36. CEC, *Proposal for a Council Regulation on a Community Action in the Field of Telecommunications Technologies: RACE* , COM (86) 547 (Brussels, 1986), pp. 20−21.

37. Interviews.

38. For more detail on the origins of EUREKA, see Sandholtz, *High−Tech Europe* , Chapter 9.

39. *Financial Times* , October 25, 1991, p. 2.

40. A more complete analysis of telecommunications reforms in the EC is in Wayne Sandholtz, "Institutions and Collective Action: The New Telecommunications in Western Europe," *World Politics* (January 1993).

41. Paul Taylor, "Toughest Time Ever for European Players," *Financial Times* , Survey on the Computer Industry, April 7, 1992, p. 2.

42. Steven Butler and Robert Thomson, "No Winners in the Chip Race," *Financial Times* , January 21, 1992, p. 19.

43. Louise Kehoe, "Chips Are Everywhere," *Financial Times* , January 31, 1992, p. 10.

44. Paul Taylor, "Toughest Time Ever for European Players," *Financial Times* , Computer Industry Survey, April 7, 1992, p. 2; Alan Cane, "Hard Times for European Hardware," *Financial Times* , October 4, 1991, p. 21.

45. CEC, *Information and Communications Technologies in Europe* , EUR 13413 EN (Brussels, 1991), p. 34.

9—
The Japanese Semiconductor Industry

Yoshio Nishi

The semiconductor industry in Japan has two distinct features as compared with the United States and Europe. First, it has been driven by commercial applications as opposed to military applications. Second, it has been part of a large, vertically−integrated industry, but not part of an industry that manufactures semiconductor products exclusively.

The Japanese semiconductor industry must still be classified into several categories, as shown in Table 9.1. The first category is the heavy electrical industry and certain home appliances such as those manufactured by Hitachi, Toshiba, and Mitsubishi. The second category is characterized by the companies that are heavily involved in communications and, lately, in computers, such as NEC, Fujitsu, and Oki. The third category consists of consumer application−driven companies, and the fourth is mostly composed of newcomers to the semiconductor world from other established areas, which have an increasing demand for captive semiconductor capability. Pioneer and Yamaha are known for audio equipment; Seiko is famous for a variety of timepieces; Nihondenso provides electrical and electronic devices and equipment for the automobile industry in Japan; Ricoh is mostly involved in office equipment. Also, after a certain period of time, these companies are supposed to be vertically−integrated.

Table 9.1
Structure of Japan's Semiconductor Industry

Industry	*Firms*
Electrical industry, general	Hitachi, Toshiba, Mitsubishi
Computers and communications	NEC, Fujitsu, Oki
Consumer electronics	Matsushita, Sanyo, Sharp, SONY
Captive consumption only	Pioneer, Yamaha, Seiko, Nihondenso, Ricoh

The growth path in integrated circuits in Japan can be summarized as follows. In the 1960s, calculators and color televisions played an important role in driving the integrated circuit (IC) industry. Primarily, the development of calculators strongly stimulated metal oxide semiconductor (MOS) IC technology development and manufacturing, which later became a key player in the very large scale integrated (VLSIs) circuits era. MOS ICs demonstrated significant growth in the industry during the 1970s. Calculators still played a leading role and other applications, such as watches and cameras, added further features to high−density packaging. The 1980s was an era when the Japanese IC industry showed strong penetration into the industrial electronics area.

"Commercial application−driven technology" and "vertically integrated company" has significance for IC research and development (R&D) and manufacturing. To be highly competitive in IC products in commercial industry requires a higher integration density of circuits on silicon chips, which is essential for lower cost and function. Higher performance is required for more value−added products to differentiate one product from another. Lower defect density on wafers or higher manufacturing yield is again essential for low−cost products; shorter design time results in competitive time−to−market, and shorter testing time allows both shorter time−to−market *and* lower cost. Interestingly, the items pointed out above are well−

known requirements for successful VLSIs. Military applications, on the other hand, would not have required some of the above items, such as the cost−related ones. Therefore, they would not have been able to drive VLSIs correctly. Clearly, the Japanese IC industry has taken advantage of being driven by commercial, civilian applications.

Commercial competitiveness is also linked directly to vertical integration. This allows (a) more R&D resources as compared with the resources for a genuine semiconductor manufacturing firm, (b) larger R&D spending that can far exceed the "reasonable" percentage determined from semiconductor product shipments, because R&D can be diluted over the entire company's R&D spending, (c) stable, long−term strategy, in spite of periodic fluctuations of the silicon business cycle, again supported by the rest of the company's long−range business forecast, (d) capability in system level evaluation of ICs within the same company, which implies that a vertically−integrated structure can give the semiconductor community immediate feedback, and (e) a large captive market, which can act as a buffer for semiconductor business fluctuations, through which stable R&D activity could be maintained.

These arguments could be applied to some U.S. companies that have vertically−integrated structures. However, the majority of vertically−integrated U.S. companies did not choose the way that their Japanese counterparts took. It is likely that the U.S. companies have been driven by vast military applications that did not place strong cost pressure over their IC sector. Therefore, there was not a great need to expand the scope of IC manufacturing, which is essential to lower overhead costs, or to use a merit scale, as has been widely accepted. The rest of this chapter will discuss how the differences in industrial structure and needs patterns have made the Japanese VLSI industry what it is today, which is quite different from any other country.

VLSI R&D in Japan: A Successful Case History

The Japanese industrial structure had been characterized by great dependence on oil imported from OPEC countries. The first energy crisis eventually emphasized this dependence, and the economy went into significant confusion. There rose a fairly strong desire, in general, to get rid of the high−energy−consuming industrial structure and build high−technology, high−value−added industries. This trend was also accelerated by the fact that Japan has a poor supply of natural resources. As a result, the construction of a high−technology industry became almost a national theme for future survival. By this time, Japan's GNP had reached third place in the world, after that of the United States and the former U.S.S.R., which was important in sustaining costly R&D. Also important were the industry infrastructures that allowed Japan to build highly−sophisticated integrated technological and educational infrastructures, which provided a stable flow of highly−skilled human resources with engineering and science backgrounds. In addition to the points above, a strong trigger came from the U.S. when it was announced that a future IBM system would need a megabit memory. One of the key integrated circuit technologies essential to the future system was known as electron beam technology, which was published by AT&T Bell Laboratories, IBM, and other organizations. There was a large technological gap between the U.S. and Japan in the area of megabit technologies.

The VLSI R&D Program was thus planned to close the technological gap between the U.S. and Japan in future IC technology. The goal was to establish VLSI technology, which could lead to commercialization of 1Mbit dynamic random access memory (DRAM) or the equivalent by 1985. According to Dr. S. Tanaka, who was one of the initiators of the program, this was a historic turning point for Japanese industry. Before this program, industry R&D had placed a strong emphasis on commercialization, and national projects also had aimed at applied technology. On the other hand, the VLSI program had a strong focus on basic technology, which would strengthen Japan's capability to build its own technology rather than relying upon imported technology. The program started in 1976, and ¥74 billion was spent until 1979, of which 40 percent was subsidized by the Ministry of International Trade and Industry (MITI). Note that the total annual sales of Japanese semiconductor products in those days was ¥350 billion, which can be translated to 20 percent of sales spent for this program on top of their regular R&D spending. The other significant feature of this program is that this was the first multicompany effort directed at research and development technology in the semiconductor industry in Japan. The research areas were device, process, materials, design or testing, and packaging, which covered all of the key ingredients for VLSIs as listed in Table 9.2. Five companies, NEC, Toshiba, Fujitsu, Hitachi, and Mitsubishi created two "group laboratories" and a "central laboratory," as shown in Figure 9.1.

Basic research and development was done at the VLSI Cooperative Laboratory as central research. The NTIS and CD Laboratories served as receiving

Table 9.2
Japan's VLSI Program

Device
High density memory: MOS
High speed memory: bipolar
High density logic: MOS
High speed logic: bipolar
Process
Submicron lithography: optical
E−beam
X−ray
Submicron etching: dry process
Submicron thermal processes
Interconnection/metallization
Materials
Large diameter silicon crystal
High performance epitaxy
Ultra clean processing
Design and testing
CAD for logic/circuit/layout
Design verification
Highly automated testing
Package
High density
High speed

organizations for the results established at the VLSI Cooperative Laboratory, as well as an applied research and device development organization. Major achievements coming from the VLSI Cooperative Laboratory were the following:

Electron beam raster scan system

Electron beam projection system

X ray lithography system

Single wafer multichamber plasma etching system concept

Laser scan failure analysis tester

Infrared scanning microscope for wafer temperature measurement

PSA MOS transistor

Quadruplicate self−aligned stacked high capacitance cell

Submicron device physics or reliability

Some of these developments later resulted in a strong position for the Japanese VLSI industry.

Major achievements in the NTIS Lab and CD Lab were the following:

65Kbit DRAM or 256Kbit DRAM prototype

10Kbit DRAM or 256Kbit DRAM prototype

10K gate 16 bit MPU

2μ process technology integration verified through VLSI chip fabrication

Submicron process feasibility and unit process research

CAD tool capability for logic, circuit, pattern, or test of VLSI chips

The items mentioned above are already well known. However, important points should be made, as illustrated in these valuable lessons:

The importance of building a long−term strategy and implementing it by keeping sufficient R&D resources and funds in spite of fluctuations in the business environment

Intercompany, university, and government lab interaction

Interaction mode with equipment industry

The long−term strategy that is now commonly accepted as one of the key management features of Japanese industry probably had been established at that time, with business experience developing subsequently.

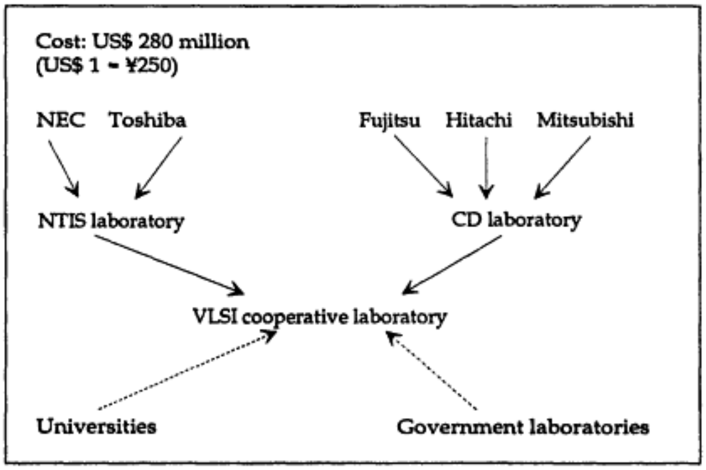

Figure 9.1
MITI VLSI Program, 1976−79

Before the VLSI Program, the Japanese industry planning process was, as far as the author has experienced, not a farsighted one. The concept of consortia was not popular at all by that time. Engineers and managers assigned to the program, especially working at the Cooperative Lab, and to some extent, even at the NTIS and CD Labs, started to work with uneasy feelings and some confusion about working with assignees sent by competitors. Eventually, they established their own reasonable mode of interaction, which again has strengthened their position in creating other long−term programs, such as Future Electron Devices, Optoelectric Devices, SOR Technology Consortia, and Superconductivity Research.

Consequently, the VLSI Program contributed greatly to the Japanese semiconductor industry, both directly, in terms of its research and development achievement, and indirectly by building a new culture for R&D planning and collaboration. It is also important to know that the company R&D expense for this program came from their headquarters, not from their operating divisions, which allowed them to support the program even in a slow business period, and also to spend money in addition to their regular R&D spending. Involvement of equipment manufacturers was also key to managing the program successfully in terms of ease in technology transfer from R&D to manufacturing, which will be reviewed later in this chapter.

VLSI Technology Trend in Japan

The basic trend of the VLSI technology development in Japan is fairly simple. Figure 9.2 shows how the minimum feature size evolved over time. The interval of two technology generations has been about 2.5 years. With few exceptions, most SRAM (static random access memory) and DRAM make a pair with a fourfold increase in bit density. SRAM as a cache memory for computers, and DRAM as a main memory, are really proceeding together. The role of DRAM as a technology driver has become clearer beyond the 64Kbit DRAM era, which eventually coincides with the interim goal of the Japanese VLSI Program, as discussed briefly in the previous section.

Another important feature of VLSI technology in Japan is the early introduction of complementary metal oxide semiconductor (CMOS) technology. As shown in Figure 9.2, the first CMOS VLSI was implemented in SRAM. Even before the VLSI era, Al gate CMOS was commercialized in the early 1970s for calculators and watches, followed by logic and PLA, as well as microprocessors. Based upon those foundations, CMOS VLSI soon became a mainstay of Japanese VLSIs. DRAMs, which had been considered the territory of NMOS, also moved to CMOS in the mid−1980s, resulting in 1Mb DRAMs. The early start of CMOS in Japan certainly accelerated the progress of VLSI technology in Japan. Figure 9.3 shows how the relative

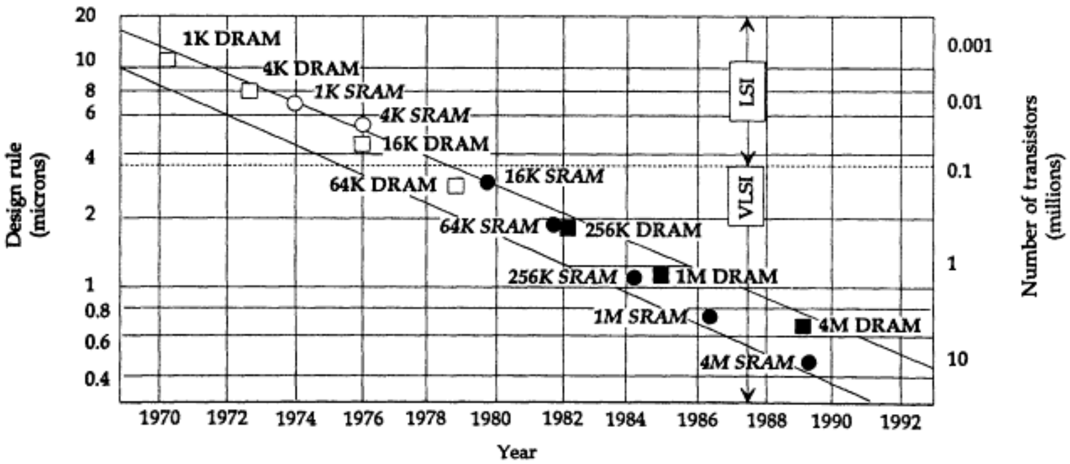

Figure 9.2
Evolution of Design Rule and Number of Transistors vs. Calendar Year, 1970−92 (solid circles and squares represent CMOS, others are FET)

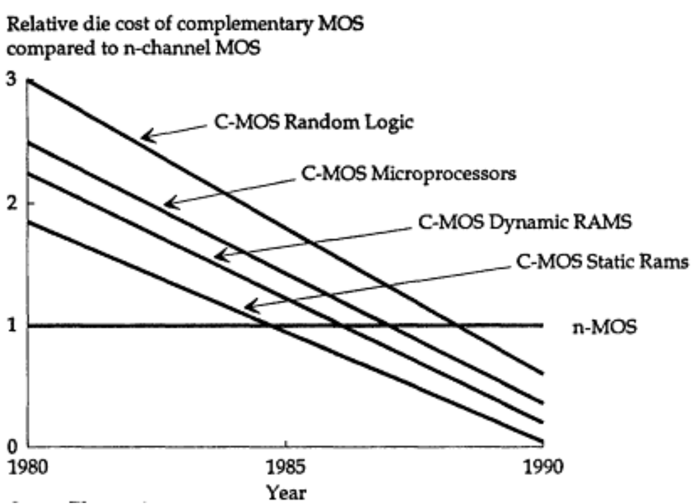

Figure 9.3
Relative Cost of C−MOS Chip as Compared to N−MOS
Source: Electronics.

cost of CMOS has come down to beat NMOS, which was supposed to be the least expensive technology. Progress in the optical stepper−based lithography technology has helped to obsolete one of the important concepts: that chip cost is determined by the number of photolithographic steps. This concept had been true until stepper technology was introduced, because the number of defects on a chip was proportional to the number of photomasks. After the introduction of the stepper, this became less important than previously. This change also accelerated the move from NMOS, which did have fewer mask steps but far better noise immunity and less power consumption.

Another characteristic of Japanese VLSI is its conservatism in technology choice. Japanese industry has been quite aggressive in undertaking R&D for VLSI technology, and a significant percentage of important international conferences have been filled with technical papers from Japan. However, once the firms decide to make a technology choice for manufacturing, they have consistently chosen the most conservative technology as long as that choice met the performance requirements. This has probably been encouraged by their mode of R&D−manufacturing interaction, where a bilateral flow of engineers within a company between different functions was established as a part of their growth path. In fact, winners in the DRAM race have been the ones who made this kind of choice. After considering the nature of VLSI, which follows the learning curve, manufacturability was the final decision criterion. Otherwise, it would have resulted in a high−performance chip with low manufacturability, which could never be placed in the market, except perhaps a specialized market, such as for military applications. In this case, it is difficult to expect any leveraging from military to commercially competitive technology and products. Eventually, Japanese VLSI had to go through the most appropriate path due to the lack of military applications, which was greatly to their benefit.

The different approaches for developing VLSI technology should be examined. Considering the design rule set as the major output of VLSI technology R&D, there are two typical but different approaches. A top−down approach starts from building a system architecture to meet system performance requirements. Then comes logic design and circuit design considerations to yield desirable design rules as goals for the process technology community. A bottom−up approach, on the other hand, starts from basic process feasibility research based on physics, chemistry, metallurgy, and other related disciplines. Then, device structure is made in order to try out new processes as well as new device concepts. At the same time, manufacturability is thoroughly tested before reaching the design rule set. The Japanese approach to VLSI is closer to the bottom−up method, which serves to secure its manufacturability.

On the other hand, the U.S. approach, especially in the case of captive suppliers, has been closer to the top−down approach, which sometimes reaches a design rule that tends to be more advanced, but less manufacturable. Both approaches have merit.

However, the bottom−up approach has definite advantages for VLSI technology, which are again related to manufacturability. In fact, progress in VLSI has relied largely upon the progress in many areas of unit process technology, as listed in Figures 9.4 and 9.5. Figure 9.4 classifies unit process technologies into four major areas, namely active device, isolation, interconnection, and physics or circuit−oriented issues classified as reliability. This is a somewhat crude classification, but it still maps a variety of VLSI activities on an actual chip area. Figure 9.5 categorizes VLSI research activities into several key synthetic process and analytical areas. Japanese VLSI activity has covered these technical areas in both tables, whereas some weakness in the design tool area might have reflected the difference in the approach to VLSI R&D, as mentioned earlier.

Figure 9.4
Key Areas of VLSI Technology

Action region:	MOSFET, NV Memory Tr.
	Scaling: X_j , t_{ox} , L, W
	V_{cc} , hot carrier
	parasitic capacitance/resistance
	μ_{FE}
	v_t
	Structure:
	LDD, buried S/D, Schottky S/D

	low−temperature operation
Passive region:	Device isolation
	LOCOS, trench, SILO
	SWAMI, FIPOS
	BOX, SIMOX
	SOS
	SOI
	CMOS well isolation
	P, N well
	twin−well
	retrograde−well
	trench
Interconnection:	Refractory metal/silicide barrier
	multi−level/contact/via plug
	coincident contact/via surface
	planarization
	new materials
Reliability:	hot carrier
	radiation damage
	latch−up
	electromigration
	soft error

Technology Drivers

The concept of "technology driver" came after industry had already taken the necessary action to find a good balance of R&D among a large number of unit technologies, as illustrated in Figure 9.4. Technology progress in integrated circuits has not been accomplished in a smooth, continuous trajectory. It has been clone in bits and pieces in current technology. It is just like climbing a stairway. Every two to three years a new technology generation is introduced and will continue until silicon technology reaches the ultimate barrier at which a switch must be made to another active device or materials to handle information and implement electronic circuitry. Each advance in unit technologies has required that a variety of technologies be integrated into one set of processes for building desired circuits. In order to make this happen, there must be some vehicle that can continuously stimulate the balanced progress in unit technology toward integration and also finance necessary expenses, where the key features are higher density, higher performance, and lower cost. Japan eventually chose DRAM as the vehicle and later it was named the "technology driver."

The important ingredient in being a technology driver is having a clear, predictable goal for density, performance, and cost. Otherwise, the driver would misdirect the whole technology. DRAM, as a matter of fact, has had excellent features in terms of the above conditions. It is a key component for any system where data needs to be stored; it works with computing systems as a main memory; advances in bit size or chip cost and required volume are predictable, and thus, easily translated into integration density, performance, and cost. The technologies used for DRAM are almost guaranteed to be used in any other integrated circuit, except for power devices. Huge production volume coming out of DRAM has strongly supported the necessary, ever−increasing cost of R&D, as well as huge manufacturing capital investment. The Japanese VLSI industry has taken full advantage of having DRAM as the technology driver.

What will be the technology driver of the future? There is a strong possibility that future microprocessors and their associated families of chips will include more memory capacity on each chip, and that memory chips will include more logic functions. Thus, since dynamic memory tends to have quite a unique structure for a cell, which is clearly set apart from other chip technologies, it is somewhat unlikely that dynamic memory development will continue to drive IC technology evolution. Still, there is a strong trend to increase

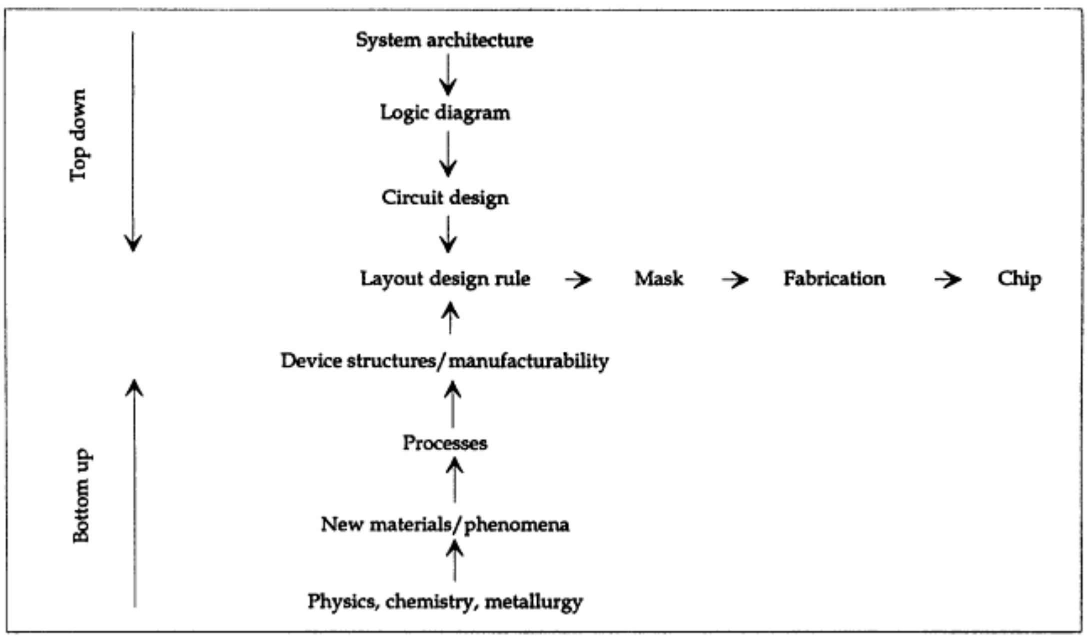

Figure 9.5
Key Process and Analytical Areas of VLSI Research

density on dynamic memory chips with smaller cell size, but mostly by a three−dimensional structure. Also, there is a continuous demand for microprocessors to increase the number of FETs on a chip. The fact remains that both dynamic memory and static memory will require higher FET density per chip in the future and that VLSI logic circuits will require higher interconnection density and an increased number of metal layers.

A significant aspect of the previous technology driver, dynamic memory, is that each generation's production and sales has provided the R&D funds essential for the evolution of IC technology itself. The R&D period for one technology generation used to be three years, but is now increasing. Yet every new technology generation still appears every two to three years. This is made possible by overlapping the R&D schedules for successive technology generations and puts an increased emphasis on selecting technology drivers that will provide the funds to support further R&D.

Hence, there may not be any unique choice for a technology driver under diverging system requirements. It is, however, natural that a more system−oriented company will choose static memory as a technology driver with the expectation that such technology will migrate in a more flexible way into microprocessors and application−specific ICs, which can make highly value−added products, through which essential R&D funds will be generated. There is evidence that Japanese industry has recognized the above situation, and that they might have dual technology drivers in the near future.

Technology Transfer

Transfer of technology from an R&D organization to a manufacturing organization has been attracting serious interest of late, as there happens to be a large bottleneck in the flow of technology that prevents industry from running a highly−efficient operation in terms of return on investment in R&D. Japanese industrial and social cultures have had certain advantages in the flow of technology. There are two aspects involved. One advantage is organizational, and the other is more personal. Traditionally (although it never worked properly), the method of technology transfer was to create a large volume of documents that contain descriptions of technology, detailed breakdowns of technology, and engineering and operating know−how about materials, processes, and designs. There is a simple, but quite essential paradox: the more perfect and complete the document, the thicker it becomes, resulting in a document that is almost unreadable within a reasonable time frame. A more acceptable and realistic way of transferring

technology is to move people from the R&D organization to the manufacturing organization. This can effectively avoid many administrative complications between the two organizations; one is a transmitter, the other a receiver. In order to make this happen, there should not be any major psychological barriers or differences in the value attached to working in either organization. In Japanese industry, there is a certain understanding that a move of this kind is a promotional rotation. People who invent or develop a new idea or technology tend to be well accepted by the manufacturing organization after completion of their work in R&D. Also, the average wage in manufacturing tends to be higher than in R&D, when comparing the same academic education at the same age. This encourages the successful engineer to .move from R&D to manufacturing with a greater opportunity for promotion to a higher position than he might get by remaining in R&D. Semiconductor manufacturing is highly dependent upon the quality of equipment and facilities. However, in the final analysis, the difference is in the quality of people in manufacturing. Japan has clearly taken advantage of this due to their industrial and social culture. Organizational improvement, as seen in Japan, involves creating a laboratory that bridges genuine R&D and manufacturing. Toshiba's Semiconductor Device Engineering Laboratory is one example. The idea is to combine design capability and process integration together in one organization that accelerates VLSI R&D and technology verification through prototype VLSI chip development. Once technology and design are proven through a real VLSI chip, it would be a smooth transition to migrate that technology to the manufacturing environment for further product family building. This also promotes the working together of both the design and process communities at the very beginning of a new technology generation, resulting in shorter time−to−market. The combination of this organizational improvement and transfer of people has significantly helped Japanese R&D and manufacturing productivity.

A further factor that should be mentioned here is the powerful Japanese manufacturing engineering activity. This consists of equipment R&D and evaluation with vendor−VLSI manufacturer coupling, clean facility hardware planning and maintenance, robotics for wafer transfer or loading, quality evaluation procedure improvement for direct and indirect materials, and computer−assisted manufacturing process control and materials inventory control. Recent computer−integrated manufacturing (CIM) efforts in the U.S. will add a certain capability to U.S. VLSI manufacturing, but the final quality of manufacturing, such as defect density on a chip, and manufacturing yield, is governed by the quality of hardware. If CIM can reduce part of the manufacturing cost, the saved cost has to be reinvested in hardware to minimize defect density, minimizing equipment−borne process parameter fluctuations.

Conclusion

VLSI is now a big science and technology that almost refuses to recognize individual effort, forcing team effort to achieve a goal. Under such conditions, Japan has the advantage over major competitors of being a more homogeneous nation and having an industrial and social culture more suited to the nature of VLSIs. Part of this culture was built up through the VLSI Program, which generated a consortium and joined organizations attached to member companies as a new way of responding to this big science and technology. Japan was also in a crisis of national survival as a high−technology country, prompting the VLSI Program and subsequent consortium efforts in many other areas. The choice of a technology driver, and efficient technology transfer, were key features of successful VLSI R&D and manufacturing.

10—
The U.S., Japanese, and Global Integrated Circuit Industry: Prospects for New Entrants

W. Edward Steinmueller

For nations that plan to be significant users or producers of integrated circuits (ICs), the coming decade will offer major opportunities and pitfalls. This chapter analyzes the origins of U.S. and Japanese industries' leadership positions, the catchup efforts of newly industrialized economies (NIEs), and the current state of international competition that is shaping opportunities for new entrants. The different roles of government policy in the United States and Japan are a central theme in this chapter.

For most of the IC industry's history, U.S. policies focused almost exclusively on providing a fertile commercial infrastructure for the IC industry. Until recently, U.S. policy has relied on market mechanisms for generating new IC process technologies, and for assuring their adoption by the public and private sectors, an experience that is examined in the first section, Market Mechanisms in the United States. Governments that aim to reproduce the innovative performance of U.S. firms must encourage, or devise substitutes for, the market mechanisms that have been responsible for technological progress in the IC industry.

During the past decade, Japanese IC producers have employed government programs and a vertically coordinated industry structure to catch up with U.S. firms. Some analysts are convinced that the policies utilized by Japanese firms and the Japanese government are a major departure from past U.S. policies and are a panacea for other nations seeking to catch up with the United States. Indeed, the U.S. government has responded to Japanese efforts and the appeals of U.S. firms by imitating Japanese government policy. The second section, Competition between the United States and Japan, examines international competition between producers in these two countries by identifying the strengths of Japanese government policies and how the U.S. government has responded to the challenge of Japanese competition in the IC industry.

The market−led mechanisms examined in the first section and the international competition between U.S. and Japanese IC firms discussed in the second section provide a foundation for discussing the policy options available to developing nations. The third section, Development of the Integrated Circuit Industry in Newly Industrialized Economies, comments on the catch−up efforts of such economies and reviews some of the policies that they have employed. The fourth section, Policy Recommendations for New Entrants, offers policies for exploiting promising opportunities and avoiding likely pitfalls in the IC and electronic systems markets during the remainder of this century.

Market Mechanisms in the United States

The technological leadership of the U.S. industry over three decades reflects technological competencies and opportunities that other large nations could have reproduced or imitated. Market mechanisms, not sheer technological prowess, have played the central role in sustaining U.S. leadership. It must be admitted, however, that the U.S. lead in developing IC technology and its leadership in scientific and technological developments in materials science, applied physics, and chemistry were also important foundations for staying ahead.[1]

The three economic features that appear necessary in building a successful high−technology industry are (a) prolific generation of innovative initiatives, (b) the absence of delay in abandoning uncompetitive technological initiatives, and (c) rapid adoption and utilization of new innovations. All these components appear to be necessary for a nation to achieve a leadership position in IC production. For nations engaged in catching up with the industry leaders it may be possible to focus efforts on reproducing the leader's experience. But even in catch−up efforts, decentralization and independent technological development efforts are useful.

Why is a "prolific" generation of innovative initiatives necessary for building a high−technology industry? In can be argued that the number of technological problems for which ICs are the solution must be finite, and might even be somewhat limited in number. Employing scarce investment resources to create numerous technologies that have limited or nonexistent applications appears inefficient. This perceived inefficiency offers a superficial appeal for centrally coordinated investment policies that restrict the number of development projects from the outset.

Restricting the number of development projects undertaken requires a forecast of the "winning" technology. When the "winning" technology has been revealed by market success of leading nations, it may be reasonable to focus efforts on duplicating this experience. For development of a leadership position, however, the belief that winning technologies can be reliably forecast is fallacious. Whenever a forecast is made, there are many available speculations about the possible success of alternative technologies. In fact, there is seldom a convincing economic or technological basis for choosing among these alternatives at an early stage of development. A rapid rate of technological progress at the technological frontier occurs when market conditions make it possible to support diverse technological development projects, and when the underlying technology continues to be fertile in producing technological advance.

Second, while the absence of delay in abandoning uncompetitive technological initiatives is taken for granted in market economies, it is essential for either a rapid pace of technological progress or successful catch−up efforts. The incentives for abandoning failed initiatives are difficult to establish in centrally planned or managed technological development efforts. In the United States, the market mechanisms that provide incentives for technology development projects have also proved to be effective in winnowing unsuccessful projects.

Third, to sustain the pace of technological advance, neither the prolific generation of technological development projects nor the absence of delays in the abandonment of failed projects is sufficient. Innovation and commercialization must be sustained by a rapidly growing and technologically dynamic market that will adopt innovative products. As producers of intermediate goods for electronic systems producers, IC companies have been favored by an increasingly competitive and innovative market in electronic systems products. A major policy debate has arisen between those who believe that these markets must be domestic and those who believe that an international division of markets is possible. This debate is examined in the second section of this chapter, since it is central to U.S. company and government response to the competitive challenge of Japanese IC producers and Japanese government policies.

Of the three economic components just outlined, the first, the mechanisms responsible for generating new technological initiatives requires the most careful consideration. Two of the technological features responsible for U.S. leadership have already been mentioned: the initial leadership of U.S. firms in developing IC technology and the infusion of scientific knowledge from related fields. Three market mechanisms have been critical in building the U.S. IC industry: (a) a high variance in the commercial success of technological development projects coupled with rapid market growth, (b) the means for appropriating economic returns from innovations, and (c) the absence of barriers to financing new development projects. These market features have been essential in motivating the sustained investments in new process and product technology in the U.S. IC industry.

What is the relationship between variance of returns on technological development projects and market growth? For 30 years, technological development in the United States in the IC industry has been accompanied by rapid growth of output markets rather than extraordinary profitability. Firms that have sought to advance the state of the art in IC design and production have been able to overtake those that focused on fully developing current technology. The lesson of this experience that was transmitted to U.S. IC producers was that innovation rather than manufacturing efficiency offers the best hope for sustained growth in the IC industry. At the same time, success in innovation has not conferred a position of technical leadership to individual firms.

A common view of the IC industry is that variance in the commercial success of individual firms is the result of their success or failure in achieving major technological breakthroughs. Several IC producers have profited from major breakthroughs in microprocessor product design, bipolar and

complementary metal oxide semiconductor (CMOS) process technology, and the development of dynamic, static, read only, and electronically erasable memory technologies. No single firm, however, has been able to achieve dominance in the industry by making major technological advances. Moreover, the commercial significance of such breakthroughs for individual firms can easily be overstated. IC technologies, like many other manufacturing technologies, are amenable to commercially important technological improvements that are not breakthrough technologies or major innovations.

The value of both incremental technological improvements and breakthroughs are determined by the extent of their applicability, which is highly uncertain. Systems producers—computer, industrial equipment, telecommunications equipment, scientific instrument, and consumer electronics companies—compete in hundreds of submarkets. The applicability of any single IC product, even when focused on a particular systems submarket, may be unexpectedly broad or narrow depending on the evolution of these systems submarkets. The *a priori* prediction of commercial success for any particular IC is therefore extraordinarily difficult. The products of any IC company may succeed or fail due to rapid or slow growth in a submarket, the creation of satisfactory substitutes by other IC companies, or the discovery of unanticipated applications for an IC in systems products. Market growth has therefore accompanied and reinforced the variance of returns to technological development.

To cope with these uncertainties, IC firms have developed competitive strategies that seek technological breakthroughs while, at the same time, efficiently following the innovative leads of others, incrementally improving upon existing techniques with the aim of reducing price, increasing performance, and developing products that are technological complements to major breakthroughs.[2] Much of the commercial success of individual firms depends on their relative performance in exploiting these sources of commercial return. The high variance of returns across firms in the IC industry is the result of markedly different success in incremental and complementary innovation and in the less frequent incidence of success in breakthrough innovation.[3]

The variance of commercial returns among firms in the U.S. IC industry is therefore the result of two economic forces. On the one hand, the growth of electronic systems submarkets has been volatile, providing windfall gains and losses for individual IC producers. On the other hand, major advances and incremental improvement in product design and process technology has allowed many firms to establish and extend technological capabilities that support a broad range of product offerings. The resulting division of economic and technological leadership has forestalled the domination of the U.S. IC industry by any single firm or small group of firms.

The historical limits on this ability to appropriate economic returns is the second important mechanism sustaining technological advance. If the creators of breakthrough innovations could successfully leverage their discoveries into unique positions of advantage, that is, positions of market power, within the industry, the market mechanisms responsible for the diversity of the industry would dramatically change. The sources of these limitations and current trends have been discussed elsewhere.4 The ability to capture such returns might bring with it abilities to manage the pace of technological advance, the introduction of substitute products, and the rate of price decline. Of course, all of these abilities would come at the expense of systems producers and the ultimate consumers of electronic systems products.

The last mechanism in the market system that has characterized the U.S. IC industry—modest barriers to the financial investment in new technological development projects—has reinforced competition in the industry and forestalled the emergence of market power within the industry. Until recently, the investment cost for entering into IC production was comparatively modest, and the industry fostered new start−ups in many of its diverse product segments. In comparing the United States with other nations, it is a common observation that few nations have a developed venture capital sector. In the United States, venture capital has reduced the barriers to finance of young firms by providing an early and speculative market for the sale of equity. Early venture capital finance of new firms also requires an active initial public offering market that assures the eventual liquidity of venture investments. Venture capital and initial public offerings serve the critically important roles by decentralizing decisions about the "right" means to achieve a successful technological outcome and by supporting the creation of new start−ups, which exert competitive pressure on the industry as a whole.

Most start−ups have begun with a relatively limited repertoire of products. Some start−ups succeed in substantially broadening their technological and market base over time. More important, however, is the competitive pressure that these firms offer to incumbent firms. New firms often pioneer the pro−

cess technologies or product opportunities that, while not ignored, might otherwise be less vigorously pursued by incumbent firms. Incumbent firms most often choose to improve on or match the successful innovations of new firms. The re−suiting competition is an important addition to the market mechanisms responsible for the rapid technological progress in the U.S. IC industry.

Each of the mechanisms just examined has powerful and direct effects on the technological progress of the industry. In addition, they may act in concert. One illustration of these combined effects is the relationship between the incentive to seek out breakthrough technologies, the difficulty of appropriating returns from making a breakthrough, and the incentive to pursue non−breakthrough advances. The commercial returns available to firms from pursuing strategies other than searching for a breakthrough are a direct re−suit of weaknesses in the ability to appropriate economic returns from previous breakthrough innovations. Ironically, the diminution of incentives to pursue breakthroughs results in an increase in the incentives to invest in other forms of innovation. In the U.S. industry, there is a well−established historical pattern of cross−licensing, second sourcing, and other technological exchanges that reduce the market power of leading firms. Technology exchanges have increased the competitive vigor of the industry and, arguably, produced a more rapid rate of technological progress than would have been attained if innovators had been able to monopolize their discoveries.5 The motive of leading firms to engage in technological exchange is economic. By broadening the portfolio of technologies through exchange, firms assure that they will not be left out of major developments.

The historical pattern of technology exchange in the IC industry may now be undergoing substantial alteration as the result of legal and technological change. Legal protection for breakthrough technologies will receive more effective intellectual property protection as the result of recent changes in U.S. patent and copyright laws as well as a growing disposition of courts to enforce such rights. At present, it is uncertain whether such protection will give any single firm market power relative to rivals or whether innovating firms, seeking to increase their own direct returns on innovation, will continue their historical pattern of technological exchange.6 The extent and outcome of litigation among larger firms, and between incumbents and new entrants, will be an indication of how the legal environment will shape the environment in coming years.

A second illustration of possible changes in the incentive structure responsible for rapid technological progress in the industry involves the possibility of capturing a sustainable lead in process technology. Ultimately this illustration is relevant to the competition between the U.S. and Japanese IC industries. It is useful, however, to begin with a more general analysis.

Throughout the history of the IC industry, technological developments have offered opportunities for capturing a technological lead that might be translated into market power. That this potential has failed to materialize should not be taken as proof of its impossibility. The promise that such a development might occur in the next wave of technological improvement has been an important incentive for continuing investment in technological advance. Ironically, success in attaining this goal carries with it the possibility of attenuating the incentives for further progress.

The most likely prospect for capturing a sustainable lead in IC technology would be the development of leadership in a process technology that would provide the successful innovator(s) with the capability to design a wide variety of technologically superior products. In principal, such a leadership position would create barriers for new entrants and reduce the competitiveness of firms unable to match this leadership position. What conditions would be necessary for attaining such a leadership position?

First, translating process leadership into market power requires a mechanism to limit the diffusion of the knowledge to other firms. If other firms can reproduce the knowledge underlying leadership, the forging ahead of competitors will only convey temporary advantage to the leaders. As noted above, past experience in the industry is consistent with extensive, not restricted, interfirm spillovers in the form of cross−licensing and pursuit of alternative technological development projects. More extensive intellectual property protection might, however, create a means of restricting transfers and altering the incentives for new technology creation.

Second, in the absence of a mechanism for appropriating the returns from process leadership, the pioneering firm must be able to realize the gains from that position by delivering large volumes of output to the market. Without a means of appropriating returns from process leadership, only the largest firms in the United States, Japan, and Europe are likely to be in a position to exploit their leadership positions. Firms in other nations (with the possible exception of the Republic of Korea) are simply too small to mount the investment

in the wide range of product designs necessary to capitalize on a position of process leadership.

A final barrier to the realization of market power through process technology leadership is the potential for competitive alternatives. In principal, the industry might support more than one leading process. Historically, this option has not been tested because leading firms have held a portfolio of all of the relevant process technologies. No firm has been able to get far enough ahead in any single technology to translate a leadership position into sustained market power.

Because capturing a dominant market position through process innovation is unlikely, firms in the U.S. IC industry have historically focused on two strategies; first, creating product innovations to tap the growth of electronic systems markets and second, on process innovations that would allow greater complexity in individual IC components. The flexibility of the market systems in redirecting resources for successful firms, and the rapid growth and diversification of demand for IC products have facilitated these strategies.

The ability of market systems to adapt rapidly to changes rather than staying the course on a plan based on prior expectations is a key to their success in rapidly advancing technology. The failures of several major government−sponsored projects in Europe and one in Canada during the 1970s illustrate the difficulty of achieving innovative performance through coordinated planning. The success of U.S. firms in advancing the technological frontier of IC production has relied on continual abandonment of failed initiatives including customized large scale integrated circuits (LSI), bubble memory, numerous microprocessor designs, and hundreds of smaller projects.

Centrally planned economies or centrally coordinated technology development efforts resolve disagreements before investment of social resources. Resolving disagreements takes time and consumes resources that might be invested in exploring the feasibility of alternative projects. The skills necessary to achieve consensus may have little or no relation to those necessary for choosing correct paths for technological development. Once launched, projects selected by these methods suffer from the same problems of moral hazard and research management that confront major investment efforts in market economies, but without the benefit of diversification in development projects. Choosing to limit the number of development projects at the outset constricts the supply of competing alternatives, reduces the probability of discovering the most successful alternative, and reduces the competitive pressures to improve products. These problems are particularly acute in the IC industry where the commercial returns of development projects are subject to high variance (or uncertainty). One illustration of these problems from U.S. experience is particularly germane. Twenty years ago, predictions of future IC industry developments were based on the expectation of rapid proliferation of specialized designs for large scale ICs. This prediction, based on prior experience, proved inaccurate due to a single major breakthrough—the microprocessor.

The invention of the microprocessor in 1971 and its use as a general−purpose device destroyed expectations that new systems applications would require proliferation of specialized ICs. Technological breakthroughs, such as the microprocessor, change the path of technological development. While infrequent, the occurrence of such breakthroughs make it impossible to provide blueprints for the development of technology. Some strategies will fail for no other reason than their backers' failure to anticipate a technological revolution that is currently unforeseeable. Recognizing the likelihood of such breakthroughs and acting at an early stage in their development is the best means for limiting losses from their effects.

The market mechanisms operating in the U.S. market would not have been as effective without the rapid adoption and utilization of new innovations by a rapidly growing and technologically dynamic market. ICs are a major contributor to the worldwide information technology revolution that has reduced the costs of acquiring, storing, processing, and distributing information. The electronic systems producers, whose outputs are these information technology products, have employed ICs as intermediate goods in making technological advances. The performance per U.S. dollar of ICs has increased at a rapid pace for 25 years. Moreover, innovations in the architecture, interfaces, and software of systems products have provided the IC industry with a stream of opportunities for refreshing and extending the incentives to make product innovations.

The competitiveness of IC production has also had a salutary effect on competition among systems producers. For the past 15 years, the IC industry has sought to create ever more complex "systems on a chip." In addition to reducing the final costs of systems products, this effort has enabled hundreds of new systems companies to enter the electronics industry, many of which have survived the rigors of competition to grow to maturity. The resulting competition has accelerated the pace of systems innovation in the electronic systems industries.

The result of these interactions has been an enormous industrial expansion that has propelled electronic systems companies into the ranks of the largest manufacturing companies and that has made the electronics sector the largest employer of all U.S. manufacturing industries. Indeed, the electronics industry is an excellent example of the role of new industries in long−term economic growth. The faster growth of new industries is the primary means for achieving sustained economic growth. The importance of the electronics industry to the U.S. economy heightens the significance that has been accorded the recent ascension of the Japanese IC industry.

Competition Between the United States and Japan

The advantages and some of the hazards of market systems are apparent in the development of the world semiconductor industry. The U.S. semiconductor industry led the world pace of technological advance for 30 years, from the invention of semiconductors at Bell Laboratories in 1948 to the late 1970s. During the last decade, technological leadership has been increasingly shared between U.S. and Japanese companies. Companies in Europe and in NICs have also been closing the technological gap in some IC markets.

From the invention of the transistor to the end of the 1970s, U.S. companies led the world in product innovation and process improvement. During the late 1970s an intense catch−up effort focusing on process technology was launched by Japanese companies with assistance from the Japanese government.7 This effort succeeded in closing gaps in process leadership for some of the leading IC products. The details of this catch−up effort are important in their own right, but for present purposes, this discussion will focus on two of the features that aided the effort of Japanese companies to succeed in catching up.8 These two features are the industry's increasing capital requirements and use of market access to attain economies of scale.

Capital requirements in the IC industry began to increase rapidly during the 1970s both because of the higher costs of improving process technology and because of higher design costs of new, more complex ICs.9 Table 10.1 provides statistics on annual investments in the worldwide semiconductor industry, which includes both discrete devices and ICs. In Table 10.1, the years were chosen to minimize the effects of periodic recessions in semiconductor sales and capital investments. Increases in capital investment are recorded for each of the reported years. From 1979 to 1984, capital expenditures as a percentage of sales increased by almost 50 percent. In 1988, however, this trend was reversed. The reversal was the consequence of higher average sales prices (ASPs) for ICs than in previous years and increasing productivity of some of the larger fabrication facilities. From 1982 to 1986, the average sales price (ASP) (factory shipments value divided by units shipped) was relatively constant at $1. In 1988, the ASP had shot up to $1.25. If ASPs had remained at $1, the ratio of capital expenditures to factory shipments in 1988 would have been 20 percent. Newer and larger fabrication facilities installed in the early 1980s with high−volume outputs have slowed the rate of increase of capital expenditure per dollar in sales. This may, however, be a temporary condition re−suiting from the severe industry recession of 1985, which depressed capital expenditures in the United States and Japan below 1985 levels for both 1986 and 1987.

The previous section noted the significance of spillovers from process technology within and between firms. Rapid increases in the cost of state−of−the−art IC manufacturing facilities have made it increasingly difficult for companies to maintain a leading position in several process technologies. Moreover, Japanese firms have specialized in advancing negatively−doped (NMOS) and CMOS process technologies through the development of dynamic random access memory (DRAM) product designs using these processes. DRAMs are commercially significant, accounting for 20−30 percent of the value of IC production. They are less difficult to design and test than other ICs with similar numbers of transistors. DRAMS are therefore an excellent product for pioneering process leadership and may offer significant spillovers to the design and production of other ICs. The technological races to develop DRAM and alternative process technologies are likely to sustain IC industry investment levels of 20 percent of sales during the corning decade.

In addition to increases in capital equipment costs associated with staying close to process technology leadership, the investment costs necessary for creating new product designs have also increased at a spectacular rate. While statistics for most products are unavailable, the costs of Intel's leading microprocessor designs increased from $300,000 for the 8080 product to some $100 million for the 80386, Intel's current best selling microprocessor.10 Overall, investments in R&D in the IC industry account for 10−15 percent of sales.

Table 10.1
Annual World Merchant Semiconductor Industry Sales and Capital Investments, Selected Years

Year	*Sales (US$ millions)*	*Capital investment (US$ millions)*	*Annual investment as percentage of sales*
1979 a	9,545	1,566	16.4
1982 b	12,635	2,429	19.2
1984 c	27,000	6,390	23.7
1988 d	50,600	8,070	15.9

a . Capital expenditure estimates from William J. McClean (ed.), *Status 1985: A Report on the Integrated Circuit Industry* , Scottsdale, Arizona, Integrated Circuit Engineering Inc., 1985, Tables 2−10 and 2−11, pp. 46—47. These tables provide an estimate for semiconductor−related capital expenditures of the top 10 firms and unspecified others in the United States and Japan. U.S. and Japanese semiconductor shipments for 1979 are taken from William I. Strauss (ed.), *Status 1981: A Report on the Integrated Circuit Industry* , Scottsdale, Arizona, Integrated Circuit Engineering Inc., 1981, Table 1−1, p. 2. It is not reported whether the others category of capital expenditure (25 percent of the total) includes captives (U.S. firms that produce solely for their own use). For 1979, the value of captive production (US$2.01 billion) is excluded, but capital expenditure of others (25 percent of the total) are included. This treatment follows the treatment of sales and capital expenditures in McClean, 1985, Figure 2−2, p. 46.

b . Capital expenditure figures from William J. McClean (ed.), *Status 1985: A Report on the Integrated Circuit Industry* , Scottsdale, Arizona, Integrated Circuit Engineering Inc., 1985, Tables 2−10 and 2−11, pp. 46—47. Sales from William I. Strauss, *Status 1984: A Report on the Integrated Circuit Industry* , Scottsdale, Arizona, Integrated Circuit Engineering, Inc., 1984, Table 1−2, p. 4. The same issues as described in the previous footnote apply to the 1982 statistics. Note that others are included (again 25 percent of capital investment), and capitve production is excluded (US$3,160 million). As a result, the capital investments for 1982 are directly comparable with those reported for 1979.

c . In 1985, integrated Circuit Engineering, Inc., began estimating capital expenditures in Europe and the rest of the world (ROW) in addition to the United States and Japan. ROW includes China, but excludes the former Soviet Union. European semiconductor world market share of output and capital expenditures are 10 percent and 8 percent, respectively. William J. McClean, *Status 1985: A Report on the Integrated Circuit Industry* , Scottsdale, Arizona, Integrated Circuit Engineering, Inc., 1985, Figure 2−2, p. 46. The same issues apply as in previous footnotes. Included in 1985 capital expenditures by others in the United States is US$660 million (24 percent), and excluded captive output is US$5,050 million, making the capital expenditures directly comparable to 1982.

d . William J. McClean, *Status 1989: A Report on the integrated Circuit Industry* , Scottsdale, Arizona, Integrated Circuit Engineering Inc., 1989, Figure 2−39, p. 2−43. The 1988 value of captive producers output (US$5,090 million) is excluded, and the value of other producers' capital expenditure (US$480 million or 20 percent) is included, making the capital expenditure comparable to 1984. The significance of increases in the average sales price of ICs in 1988 is examined in the text.

During the last decade, both U.S. and Japanese companies have had to contend with equipment and R&D investment requirements that together consume 30−35 percent of sales revenue before direct costs of production (labor and materials) can be paid. Over the same period, Japanese companies have been able to achieve technological parity or superiority in IC design and manufacturing technology. This catch−up effort has been an investment race favoring companies with deeper pockets. The modest returns and high start−up costs of the IC industry make it difficult for firms to finance capacity investments and design investments at acceptable cost from external capital markets. In Japan, the largest IC companies are also the largest producers of electronic equipment.11 Returns from electronic equipment sales as well as the internal need for ICs as intermediate goods within these Japanese companies provide investment resources that are unavailable to U.S. "merchant" IC producers, those companies that sell ICs to electronic systems producers and whose IC sales are a majority of firm revenue.12

In 1988, the four largest U.S. merchant IC companies accounted for about 57 percent of the $15.5 billion in U.S. IC company sales. U.S. merchant firms coexist with "captive" producers, including the world's largest IC producer IBM, whose sales to other firms are a small proportion of output, most of which is internally consumed in IBM systems products. The value of IBM's 1988 production has been estimated at $3.7 billion.13 By comparison, in 1988, the sales estimate of the largest U.S. merchant producer, Texas Instruments, was $2.7 billion (about 75 percent of the estimated value of IBM production), while the sales estimate of Japan's largest producer, NEC, was about the same as that of IBM.14 In addition, IBM produces 83 per−

cent of the value of semiconductors that it uses in electronic systems production, making it not only large, but also relatively independent of merchant IC companies.15

The other U.S. captive IC producers are significantly smaller than IBM and are more dependent on merchants due to smaller internal purchases and greater purchases of ICs from merchant producers. The largest, AT&T, is estimated to make about $630 million of ICs and to purchase about $470 million. Hewlett−Packard and Rockwell lead the smaller captives, each producing about $250 million of ICs. Hewlett−Packard purchases some $590 million while Rockwell purchases $350 million.16 The total value of captive production in 1988 was about $5.6 billion.17 The 10 largest captive producers (including IBM) make $5.4 billion and purchase $4.3 billion of ICs.18 The largest captives therefore account for one third of the $15.5 billion in 1988 U.S. merchant IC producers sales.

While existing and recent entrants to U.S. merchant production continue to offer innovative IC designs, their ability to simultaneously keep pace with the investments necessary for large−scale production of standard designs and for financing of new designs is uncertain. This problem reflects some shortcomings in the historically important role of speculative investments by firms and venture capitalists in technology development projects. A principal barrier to either source of finance for current technology development projects is their high fixed cost relative to other investments. This result is an empirical conclusion rather than a consequence of economic theory. In theory, it should be possible to devise financial instruments to span investment alternatives and thereby raise capital even for projects that are costly, as long as they have the potential to create large commercial returns. In practice, however, decision making within firms and financial markets limit the size of such undertakings because of the problems of moral hazard and the shortcomings of contracting mechanisms in research management.

Moral hazard encompasses all the problems of assuring that the *a priori* determination of risk continues to apply for the duration of an innovative project. For example, a research team may come to believe that their project (and their jobs) are doomed, but be unwilling to convey this information to investors. Since unsuccessful research teams are typically disbanded, firms and investors are often unable to learn from their experience with past dealings with particular teams. Contracting within the firm, and more significantly, among independent agents in the economy is therefore subject to serious problems that severely constrict resources devoted to large efforts, such as the ones necessary to explore current IC process technologies.

Several financial experiments have been attempted or are being considered to improve external finance. IBM purchased and eventually sold a significant equity position in Intel, which provided an infusion of cash for Intel's investment in technology development. There have been discussions of long−term IC purchase contracts in the industry aimed at smoothing the cyclicality of demand. "Strategic partnerships" have been announced between systems and IC producers. While these partnerships appear to have focused on the finance of product design rather than on process technology, they provide a mechanism for considering solutions to the financing of broader technology development projects.

The most ambitious effort to date for remedying the costs of developing new technology has involved the formation of a research cooperative, SEMATECH, aimed at financing the research and development necessary for U.S. companies to reach or overcome the process technology lead that Japanese companies have accumulated over the last decade. SEMATECH's announced goal has been the improvement of U.S. process technology. The method for pursuing this goal was the construction of a state−of−the−art manufacturing facility in Austin, Texas, assembling a cadre of skilled engineers from participating companies, and commissioning research from many of the leading U.S. research universities.

Development of new capital equipment in cooperation with U.S. producers is also an important goal of the cooperative.[19] The catch−up effort of Japanese IC firms has dramatically advanced the capabilities of Japanese capital equipment suppliers. U.S. equipment producers, many of which are small, vertically nonintegrated companies, have found it increasingly difficult to undertake the R&D investments necessary to match the efforts of larger Japanese competitors, such as Nikon. SEMATECH is providing resources to these U.S. companies through procurement and research contracts. More significantly, one possible outcome of SEMATECH's efforts is an increase in the standardization of capital equipment, in other words, effective coordination of capital equipment specification.[20] One measure of SEMATECH's success would be the promulgation of a new manufacturing model for U.S. companies to participate in IC process leadership. Among leading companies, SEMATECH will provide useful complementary research to the portfolio of process technologies that they are exploring for future process leadership. For smaller companies, SEMATECH research may create a blueprint for attaining state−of−the−art production capability. In other words, SEMATECH may be interpreted as a major effort to preserve the current structure of the U.S. IC industry. As noted, this structure has historically conferred significant benefits to the entire U.S. electronics sector. Even if SEMATECH is successful in providing a model of process technology, the investment costs of deploying this new technology will be expensive and difficult to finance within the current industrial structure of the U.S. IC industry.[21]

In addition to finance, the other major factor contributing to the success of the catch−up effort of Japanese companies has been asymmetrical market access. In short, Japanese IC companies have been able to retain a large share of their own market while making significant inroads into the U.S. market. While this fact is indisputable, the reasons for the asymmetry are deeply controversial. U.S. firms and their trade associations, including the Semiconductor Industry Association (SIA), have vehemently maintained that U.S. access to the Japanese market is systematically foreclosed by nontariff barriers. Japanese firms and their trade association, the Japanese Semiconductor Industry Association (JSIA), have offered several explanations for the poor performance of U.S. firms in penetrating Japanese markets. At various times, the issues of product quality, reliability of delivery, and effort in distribution have been offered as explanations. The evolution over an extended period of supply relationships among Japanese companies, and the comparatively closer relationships between industrial suppliers and purchasers in Japanese manufacturing, have been a major factor in restricting U.S. firms' access to the

Japanese markets. In recent years U.S. firms have endeavored to adjust to these institutional differences. Whether these efforts have been sufficient to overcome barriers arising from national favoritism will no doubt continue to occupy a prominent position in public debate of the market access issue.

Correspondingly, penetration of the U.S. market is also controversial. While U.S. IC firms have yet to blame their customers for the success of Japanese imports, they have attacked some of the marketing and pricing strategies employed by Japanese companies. These attacks have been protested by Japanese firms as inconsistent with the free trade policies ostensibly maintained by the U.S. government. Recently, the openness of U.S. distribution channels has been questioned.[22] Despite controversy over the reasons for asymmetry in trade, the consequences of this asymmetry have become both more apparent and important with the growth of the Japanese IC market. In the last decade, the size of the Japanese production has increased from $2.3 billion in 1978 to an estimated $20.3 billion in 1988.[23] Much of this growth is a result of the expansion of Japanese electronic systems production. Japanese domestic IC consumption in 1988 was approximately $15.8 billion.[24] A large proportion of the difference between Japanese domestic IC production and consumption is exported directly to the United States, and a significant fraction of Japanese domestic IC consumption is exported to the United States embodied in electronic systems products.

IC firms, regardless of their nationality, experience economies of scale in production. These economies of scale have several sources. Most important, the improvement of yield can dramatically reduce the unit cost of production.[25] This economy of scale, realized dynamically through higher cumulative volume, is referred to as "learning" and results primarily from the incremental refinement of production technique.[26] In addition, the costs of product design and equipment investments represent fixed start−up costs. When these fixed costs are amortized over a large output, the large producer realizes unit cost advantages over smaller producers. The internal demand of Japanese IC producers represents some 25 percent of their output and is, therefore, a means of financing learning and fixed costs that underlie economies of scale. When economies of scale are coupled with a deep penetration of the Japanese market, many of the learning and start−up costs are essentially paid for before the export of products. This lowers the incremental cost of products exported by Japanese firms. When coupled with financial resources, Japanese companies' ability to undertake capital and design investment provides a formidable advantage in international IC market competition.

Arguments about the reasons for capital cost differentials and market access play a central role in policy debates about the role of domestic IC production capability in the United States. Economic theory would suggest that social welfare is greatest if the lowest−cost supplier is chosen, regardless of location. This conclusion, however, depends upon market conditions. For example, if the lowest−cost producer's prices are temporary or if their future product availability is uncertain, social welfare may best be served by favoring domestic producers, even if they are higher−cost producers. In particular, if costs of future entry are high, future market power and higher prices may erode any social savings made from current low prices. Nor does it follow that domestic purchasers will act in their collective long−term interest by choosing domestic suppliers. All purchasers may regard their own purchases as nonessential to the maintenance of domestic capability, yet collectively the impact of domestic purchaser choices may eliminate domestic suppliers. Corollaries of these arguments include strategic restriction of advanced IC products to U.S. systems producers, tying strategies for leveraging market power in one product to others, and other anticompetitive practices. As in strategic analysis with the military rivals of the United States, the issues of commercial intent and behavior of Japanese economic competitors are less important than their growing capability.

This picture of Japanese advantage arising from industrial structure and international trade asymmetry and the policy debate it has created, however, is oversimplified. An additional issue complicates economic analysis of the IC industry and makes conclusions about competitive outcome uncertain. That issue is the heterogeneity of IC products and end use markets. To understand the significance of this issue, IC products can be grouped into three categories. First, standard products include ICs produced in volume that strongly rely on the economies of scale attainable through learning and investment in process improvement. Much of the trade friction between the United States and Japan in the IC industry has focused on standard products, such as DRAM ICs. Japanese success in process improvement and management has curtailed U.S. domestic production of DRAM ICs. The exit of U.S. firms from DRAM production was followed by dumping allegations adjudicated in favor of U.S. firms by the U.S. International Trade Commission (ITC). The ITC levied retaliatory tariffs against Japanese producers that were subsequently suspended through a bilateral trade accord. Despite ensuing price increases, the major U.S. IC producers have not resumed domestic production of ICs.27 U.S. firms have, however, been able to sustain production of many other standard products, suggesting that intrafirm spillovers have not, as yet, conferred the process leadership position hypothesized in the previous section.

The second category of ICs, "design−based" products, include microprocessors and complex ICs with a smaller production volume whose economic success is determined by product features as well as cost. In design−based products, the innovative design confers substantial value to the purchaser, who incorporates the device in a systems product. The innovativeness of U.S. firms in these products has sustained the competitiveness of U.S. firms. If Japanese companies attain process leadership capable of creating spillovers that provide cost savings in the production of design−based products, Japanese firms must match their prowess in process engineering with product innovation across a broad front. Opinions about the prospect of this occurring are mixed and only time will reveal whether U.S. firms will be able to maintain a major position through product design innovation.

In the third category of IC products, application−specific ICs (ASICs), the competitive outcome is in doubt because both Japanese and U.S. firms have distinct advantages in developing these products. ASICs represent a broad class of product designs and process technologies whose common feature is the performance of complex computation and signal processing functions specialized to a particular application. ASICs allow systems producers to reduce costs and differentiate their systems products by building systems with fewer and more sophisticated ICs. Because systems costs can be reduced and systems complexity can be increased using ASICs, an ASIC−based design may have fewer and more costly ICs, yet still be less expensive and more sophisticated than a system built with more numerous but less expensive ICs of other types. Process knowledge spillover from ASIC production is more complex; neither mass production of standard or design−based products seems to determine success in ASIC product markets. Instead, the development of proprietary ASIC designs coupled with rapid improvements in computer−aided design appear to be more important for competitive success.28

Both U.S. and Japanese firms have made major commitments to ASIC production. The ASIC market requires close ties between systems designers and ASIC producers, and both U.S. and Japanese firms have attempted to reduce the costs of such ties by establishing design centers throughout the world. In recent years, Japanese firms appear to have made larger investments in the U.S. market than U.S. firms have made in the Japanese market. At the same time, ASIC product design innovation and the development of software allowing users to set ASIC specification and design ASIC−based systems are areas where U.S. firms have a technological lead. For these reasons, investment in capacity alone is unlikely to determine the outcome of this competitive struggle.

Cost reduction and design improvements in each sector are relevant for the balance among the three sectors. During the LSI era, when ICs had 10,000 logical gates, standard and design−based ICs

won this competitive battle, largely due to the usefulness of microprocessor−based designs that made standard devices "customizable." The outcome during the VLSI era, where ICs have 100,0000 to millions of gates, is less certain. A general−purpose IC innovation comparable to the microprocessor has yet to emerge from the development of VLSI capabilities. Instead, customized design and flexible manufacturing methods support competition between design−based and application specific ICs.29

Underlying the competition between these three sectors is the structure of demand for ICs. The entire history of IC developments has been marked by the concentration of major new IC applications in four areas. New consumer electronics items, including the compact disc player and video cassette recorder, are one major new application where Japanese firms dominate. A second is the development of the personal computer and related peripherals, including data communications modems and local area networks. A third is the development of industrial process control equipment including the nascent development of industrial robots. The fourth is the increasing utilization of ICs in telecommunications, including digital switching for local and branch office exchanges, and the use of digital ICs to improve transmission (for example, echo cancellation) and other developments supporting the growth of fiber optic telecommunications. The latter three areas are keenly contested by both U.S. and Japanese firms. Each of these areas presents opportunities for standard, design−based, and ASIC products.

In summary, the international competition in the IC industry has been marked by investment races aimed at generating large markets through standard products and achieving cost reduction through economies of scale. U.S. companies' initial technological lead has been eroded by Japanese firms that utilized their larger size, government support, and strong domestic market to finance increasing investment costs. U.S. firms have been able to hold part of their former dominance through continued innovation in design−based products, but their hold on this market may become tenuous as process knowledge from standard products is made available for advanced design−based products. The development of new technologies for application−specific ICs has provided opportunities for alternative economic approaches for success in IC production. The outcome of competition among standard, design−based, and application−specific IC sectors is uncertain, but the specialization of electronic systems markets is likely to provide continuing opportunities for development of new VLSI product and process innovations.

Development of the Integrated Circuit Industry in Newly Industrialized Economies

The newly industrialized economies of East Asia, Korea, Taiwan (China), Singapore, and Hong Kong have developed dynamic domestic electronics industries during the past two decades in which the production of ICs plays a growing role.[30] In all four of these economies, electronic components and systems production accounts for a larger share of gross domestic product (GDP) than in such developed countries as the United States, Japan, or the United Kingdom—in the case of Singapore, where electronics manufacture accounts for nearly 40 percent of GDP, the share of this industry in GDP exceeds the share of all manufacturing in the U.S. gross national product (GNP).

Korea is significantly more committed to producing semiconductor components and consumer electronics (these two sectors account for more than 75 percent of Korean electronics production in 1987) than any of the other three economies. Singapore and Taiwan (China), by contrast, have specialized in the production of computer subsystems. Hong Kong's electronics industry is focused on the manufacture of consumer electronics products. Korea and Taiwan (China) are the major producers of microelectronic components, especially ICs in these four economies. All four of these economies entered the production of ICs relatively recently, following the establishment within each nation of an important industry in the manufacture of systems. Hong Kong has three IC companies while Singapore has one existing semiconductor plant (an SGS−operated factory producing power transistors) and a new IC fabrication facility (where National Semiconductor is a minor equity holder).

The contrasts in these economies' electronics industries are matched by significant contrasts in industry structure and government policy, particularly in the treatment and economic significance of foreign ownership. Direct foreign investment has been important in the development of the electronics industries of Singapore and Hong Kong, both of which have had relatively liberal government policies toward foreign investment and, in the case of Singapore, policies that actively encouraged foreign investment in this sector. As a result, the development of the electronics industry, especially microelectronics, has occurred in these economies largely through the actions of foreign−owned firms. In Korea and Taiwan (China), by contrast, domes−

tic firms have been more important, although foreign investment has been an important source of technology and expertise.

Korea has followed a somewhat different path from the other NIEs in recent years, keeping a heavy emphasis on consumer electronics rather than shifting focus toward personal computer markets, and recently expanding production of micro−electronic components. Direct foreign investment in Korea was regulated for much of the postreconstruction period, and one recent review concluded that "Such investment has played only a minor part in the country's industrialization."31 During 1962−81, the cumulative inflow of direct foreign investment amounted to roughly $1.25 billion, slightly more than one−twentieth of gross domestic investment in manufacturing. Rather than foreign investment, imports of capital goods and turnkey plants were important channels of technology transfer during Korean industrialization:

Korea's policies concerning direct foreign investment (DFI) and foreign licensing (FL) were quite restrictive in the early years of industrialization, when technology was not a critical element and the mature technologies needed could be easily acquired through mechanisms other than DFI or FL (e.g., reverse engineering) . . . .

Consequently, the size of DFI and its proportion to total external borrowing were significantly lower in Korea than in other NIEs [newly industrialized economies]. For example, Korea's stock of DFI in 1983 was only 7 percent of the size of that in Brazil, 23 percent of that in Singapore, and less than a half the size of that in Taiwan and Hong Kong . . . . Korea promoted technology transfer through the procurement of turnkey plants in the early years. For example, the chemical, cement, steel, and paper industries established in the 1960s and early 1970s, all resorted to the turnkey mode for their initial setup. But Korean firms assimilated imported technologies so rapidly that they managed to undertake subsequent expansions and upgrading with little assistance from foreigners.32

Although direct foreign investment accounted for a small share of domestic capital formation, its role nonetheless was significant in some sectors, such as electronics. Many analyses of Korean industrialization emphasize the greater importance of foreign ownership in the newer, high−technology sectors.33 In response to the changing technological requirements of Korean industry (as well as pressure from foreign governments), the Korean government has adopted more liberal regulations for direct foreign investment, similar to those of Taiwan (China).34 Nevertheless, in high−technology "strategic sectors," restrictions on foreign investment are frequently accompanied by import protection and reliance on the *chaebols* (in Korea, a very large, highly diversified business conglomerate under a common controlling ownership; as a group, *chaebols* account for a large part of the economy, particularly industry).

The *chaebols* more closely resemble the prewar Japanese *zaibatsu* (in Japan, a conglomerate of companies often with a high degree of vertical integration including suppliers, banks, and trading companies, not always with formal ownership links) than they do the postwar Japanese industrial groups, inasmuch as these Korean firms are subject to stronger central management control than are the constituent elements of Japanese industrial groups. The *chaebol* originated in response to stringent government controls on capital markets during postwar Korean industrialization. Credit rationing and restrictions on foreign currency convertibility favored the development of large firms that could overcome these capital market imperfections and that could successfully lobby the institutions that controlled capital availability.35 In addition, these large firms were well placed to negotiate turnkey investment projects and original equipment manufacturer (OEM) production agreements with foreign multinationals in the shipbuilding, steel, and consumer electronics industries.

The large Korean *chaebols* have been able to enter the production of microelectronic components like DRAMs through their ability to negotiate joint venture agreements with foreign multinationals, to purchase technology licenses from foreign firms (here, the declining fortunes of several small U.S. semiconductor firms played a crucial role),36 and to absorb the enormous costs of entry into this capital−intensive sector.

As of 1987, each of the four largest *chaebols* had sales of more than $12 billion, and were among the 50 largest industrial firms in the world. Each of these large but young firms remains under the control of its founding entrepreneur or the founder's family. Mody estimated that electronics accounted for at least 20 percent of the total 1987 sales of Samsung, one of the most successful *chaebols* in IC and electronic systems production. High levels of producer concentration in the Korean economy, however, do not appear to have produced widespread anticompetitive behavior. Indeed, the Korean government appears to have exercised some care to ensure that several *chaebols* were represented in strategic industrial sectors, so that its efforts to encourage investment in these areas

through restricting imports and foreign investment would not result in monopolization of domestic production.

Average firm size in electronics and other sectors of Taiwan (China) is smaller than in Korea. Scitovsky notes that in 1981, the $10 billion in sales of Hyundai alone, one of the four largest Korean *chaebols* , exceeded the combined sales of the 10 largest industrial firms in Taiwan (China). As in Korea, this characteristic of firm structure in Tai−wan (China) reflects government policy. During the reconstruction period of the 1950s, the government of Taiwan (China) removed restrictions on domestic capital markets, resulting in high domestic interest rates and high savings rates.37 In addition, such capital−intensive industries as chemicals, steel, and cement remained under government control. High rates of household savings and a reasonably open capital market appear to have improved the access of relatively small firms to external finance, and encouraged the growth of many small firms, few if any of which are as diversified as the Korean *chaebol* . The contrasting structures of capital markets and industrial firms in Korea and Taiwan (China) have been cited as one factor contributing to greater equality in the distribution of wealth in Taiwan (China), by comparison with Korea.

The effects of these contrasting firm structures on performance in the electronics industry are difficult to determine. Mody argues that the smaller electronics firms of Taiwan (China) historically have been quicker to respond to new opportunities, but that these smaller, less well−financed firms are poorly equipped to sustain competition against large foreign firms.38 Firms in Taiwan (China) have been slower than Korean firms to enter the production of microelectronics "commodity" components like DRAMs. Even the ability of established firms in Taiwan (China) to remain in such increasingly capital−intensive sectors as computer peripherals has been questioned by some analysts.

Nevertheless, the high levels of unrelated diversification associated with the *chaebol* structure proved to be detrimental to the performance of the U.S. conglomerates of the late 1960s and 1970s.39 As Korean capital markets shed their imperfections and become more liquid, the advantages for individual firms of large size and political connections may decline. Korean firms also have earned relatively low returns in the highly competitive DRAM components business and have not been able to extend their DRAM process capabilities broadly to other lines of IC production. Based on the current evidence, it is difficult to single out the firm structure of either Taiwan (China) or Korea as unambiguously superior for economic development. More likely, either approach can prove effective, if government policy supports a competitive, export−oriented domestic economic environment capable of sustaining high levels of physical and human capital investment.

All four of the successful East Asian newly industrialized economies have benefitted from government policies that combined intervention with a consistent effort (since the 1950s) to reinforce, or at least not frustrate, the operation of market forces.40 Thus, in Taiwan (China), Korea, and Singapore, and more recently in Hong Kong, government policy has supported high levels of investment in a well−trained work force and in scientific and engineering manpower.

Other government programs for technical support training of employed workers have been expanded in recent years in Taiwan (China) in order to offset the effects of capital constraints within the relatively small firms that dominate the electronics industry.41 In this area and others, the potential contribution of human capital formation to the domestic adoption of advanced technologies, as well as its support for the domestic development of such advances, cannot be overemphasized. All four of these newly industrialized economies have also benefitted from their status as recipients of inflows of human capital, which in the cases of Taiwan (China), Singapore, and Hong Kong, involved the emigration of Chinese entrepreneurs from the mainland after 1949. In Korea, the return of scientists and engineers trained and employed abroad has also contributed to indigenous technological development.

The governments of both Korea and Taiwan (China) have expanded their investments in R&D to support research and advanced training of scientists and engineers for their domestic electronics industries. In both economies, these research institutes have aided the indigenous development of advanced electronics components or peripheral technologies that has contributed to the competitive strength of domestic firms. The Electronics Research Services Organization (ERSO) of Taiwan (China) has been an important source of new technology and trained manpower for the domestic electronic components industry. ERSO has been the source of at least six "spinoff" companies engaged in the fabrication of ICs, one of which is partly owned by Philips of the Netherlands (the Taiwan Semiconductor Manufacturing Corporation), the other five being domestically financed. These firms recently have joined forces with the ITRI to initiate a five−year program for the development of 16M DRAM fabrication technology.

ERSO also provides a wide range of technical services to firms in Taiwan (China), and has supported the indigenous development of an important advance in computer peripheral technology that proved to be unobtainable from foreign sources.42

In Korea, the Korean Institute of Electronics and Technology (KIET) and the Korea Electronics and Telecommunications Research Institute (KETRI), which absorbed many of the functions of KIET, were established after the creation of the Korean Advanced Institute of Science and Technology (KAIST), which also provided advanced training. These institutes, the first of which was founded in 1966, initially were staffed by scientists and engineers trained in foreign universities who had little familiarity with the technological problems of Korean industry and often who were far more interested in basic research than in the support of indigenous technological development and adoption of advanced foreign technologies. Over time, however, the focus of these institutes has shifted somewhat, from frontier scientific research to activities that could support the diffusion and adoption of technologies by Korean firms. In addition, the vastly improved in−house technological capabilities of Korean firms have made it far easier for the publicly financed research institutes to establish fruitful links with these firms. Indeed, Dahlman (1989) notes that a portion of KIET's semiconductor research facilities were sold to one of the *chaebols* in 1985, as these large firms expanded their independent R&D activities in semiconductors. The research efforts of the public research institutes have been devoted in several instances to reverse engineering of products manufactured abroad.43 As in Taiwan (China), government research institutes also contributed to the recent development of advanced technologies that could not be licensed from foreign sources.44

Summarizing the public policy experience of these four newly industrialized economies, there appear to be stronger elements of similarity among government policies than is true of firm structure or ownership within their indigenous electronics industries. In all these economies, government policy has emphasized the engagement of domestic firms with the international economy, as producers of goods, users of technologies sourced abroad, or as recipients of foreign capital. Among other benefits, this outward−oriented policy has increased or sustained high levels of competitive pressure on domestic firms, preventing deadweight losses associated with noncompetitive market structure and firm behavior. In the case of Taiwan (China), foreign−owned firms have accentuated this competitive pressure, with salutary effects. Government policy also has supported high levels of investment in physical and human capital. Finally, government policy has been highly flexible and responsive to change in both domestic and international economic and political factors.

What channels of technology transfer have proved to be effective in the development of the electronics industries of these four newly industrialized economies? As the discussion of firm and industry structure in Japan and the U.S. suggests, there is no single "optimal" path of institutional development. The experience of these economies suggests that there are a number of means for technology acquisition from foreign sources. Korea has been successful in utilizing OEM agreements, turnkey plants, and imports of capital equipment to gain access to foreign technology.45 These mechanisms have been somewhat less effective, however, in electronics, where joint ventures and licensing agreements with foreign firms are more common. Moreover, the outlook is for more of these alliances in electronics between *chaebols* and foreign multinationals. The feasibility of these alliances may be enhanced by the *chaebols* ' enormous size and increasing experience in negotiating international technology−sharing agreements. An additional advantage for the Korean *chaebol* seeking access to foreign technologies in high−volume semiconductor components is the willingness of small and medium−sized U.S. firms to sell their product and process technology. As and if the U.S. electronics industry spawns fewer of these start−up firms,46 however, this source of foreign technology could decline in importance. By comparison with steel or shipbuilding industries, however, obtaining additional foreign technology in the semiconductor components industry (especially in DRAMs) may entail a greater acceptance by Korean firms of substantial control by foreign firms over their technological assets in joint ventures. An alternative approach, the development within these Korean firms of a significantly stronger technology base, also is being undertaken, as in the 4M DRAM.

One of the most trenchant criticisms of the "Taiwanese model" for economic development is based on the possibility that the relatively small electronics firms in Taiwan (China) may face serious difficulties in negotiating access to foreign technologies through strategic alliances. Firms in Taiwan (China) have succeeded, however, in gaining access to advanced IC fabrication technologies in ASICs and smaller−volume components, access

that has complemented efforts to strengthen the indigenous technology base.

In all four of these economies, direct foreign investment has been an important channel for technology transfer. In Hong Kong and Singapore, government policy has been oriented toward attracting such investment with few if any restrictions and modest performance requirements. In both Taiwan (China) and Korea, initially tight restrictions on foreign investment have gradually been relaxed, although they remain significant in selected segments of the Korean electronics industry. Nonetheless, comparing the experiences of these four economies and their respective government policies toward foreign investment suggests that the strategic employment of restrictions on investment access and performance requirements, *when coupled with policies supporting exports and investment in human and physical capital* , may produce greater technological and economic spillovers from foreign to domestic entrepreneurs and firms. The specific means through which technology is transferred may be less important for economic and industrial development than the indigenous human capital assets and orientation toward export or import−substitution that are created by public policies within the recipient economy.

Finally, what can be learned from the experiences of these four economies concerning the technological linkages that are likely to be most supportive of economic dynamism and, potentially, entry into semiconductor components production? Once again, there is almost as much contrast as similarity among the four newly industrialized economies in this dimension as in others, but several points stand out. In all these economies, domestic production of electronics systems appears to have preceded entry into components production. Based on a comparison with the experiences of Malaysia, Thailand, and the Philippines, the history of electronics production in these four newly industrialized economies suggests that a history of systems production may be more important than semiconductor assembly operations alone for entry into components production. Indeed, assembly operations alone may fail to lead to expanded local activity in systems manufacture. Moreover, efforts to develop components production as a strategy to enter the manufacture of electronic systems are surely likely to fail. Components production, after all, historically has represented a rather small share of total sales or production in the electronics industry.47

The newly industrialized economies' history suggests that location is more important than the nationality of ownership of the systems production or assembly activities. In addition, the size and existence of any spillover effects depend critically on the supporting conditions created by public economic and human resources policies. Restrictions on foreign investment have played a modest role, but they appear to have been effective for development only when combined with these supporting policies.

The recent history of these newly industrialized economies' efforts to enter into components production also may shed some light on the strategic importance of vertical linkages among components design, components fabrication, and systems design and production within a single economy. Korean firms have entered the production of components in part because of concern that the sources of value−added in consumer electronics systems increasingly were being captured by component producers, and in part because of concern over dependence on Japanese sources for the "commodity" components extensively employed in systems. Do these largely economic considerations have technological counterparts? Is "co−location" within the same economy of commodity component and systems design and development necessary for international competitiveness? Since the design and performance specifications of most commodity components are fairly standardized, it seems unlikely that component and systems designers must work together in the development of either components or systems. Moreover, there appear to be few if any learning and other spillovers between the production of commodity components and manufacture of high−volume consumer electronics systems. Nevertheless, the actions of the Korean *chaebols* , which are being emulated by European producers of consumer electronics systems,[48] are based on the perception that such co−location is strategically valuable for competing at the technological frontier. Co−location almost certainly is unnecessary, however, for prospective entrants into systems manufacture (on an OEM basis, as a host for foreign−owned firms, and so forth)—as seen here, systems production does not appear to require strength in domestic components manufacture.

Firms in Taiwan (China) have taken actions to strengthen a somewhat different vertical linkage in the ASIC market, where the rapid growth of independent and foreign−owned design firms now appears to have sparked the development of IC fabrication firms. Especially in computer systems and related products, as Hobday has pointed out,[49] more and more of a given system's functionality

and performance is located on the application−specific component. Co−location of ASIC development and systems development, therefore, may be important, and the rapid growth of ASIC design firms within Taiwan (China) suggests that this technological interdependence affected firm strategies. The arguments for co−location of ASIC design and fabrication, however, are far less compelling. The very existence of independent ASIC design firms, of course, suggests that design and fabrication of these IC devices can occur independently of one another. This strategy, like the Korean *chaebols* ' vertical integration into DRAMs, is difficult to justify on technological grounds. Moreover, the economic arguments for entry of Taiwan (China) into 16M DRAM production also seem questionable.

Policy Recommendations for New Entrants

The scale of the competitive struggle between U.S. and Japanese companies to be world leaders in the IC industry is daunting. It is equally sobering to reflect on the efforts being made within the newly industrialized economies and the European Community to keep pace with this struggle. Government−supported programs in Europe and Taiwan (China), and Korean *chaebols* are making major investments in development of 4−megabit DRAMS so that firms in these economies can remain competitive. Japanese and U.S. firms are also making major investments. The likely outcome of all of these investments is sustained overcapacity for production of standardized products. The first rule of thumb for nations not currently in this investment race is to *focus on areas of specialized advantage rather than targeting state−of−the−art process capabilities* .

A strategy of developing specialized advantage is consistent with diversity in technological development efforts and is a pragmatic position for the current stage of IC industry development. In the leading nations, the size of domestic electronic systems markets is sufficiently large to recoup most investment costs. If any of the major players fails to be competitive, considerable pressures will emerge for protectionist measures. New entrants, including Korea, will be vulnerable to such protectionist measures and are unlikely, with constrained export opportunities, to build domestic demand rapidly enough to recover investment costs.

A second reason for delaying investment in advanced process technology is that no one really knows how fundamental technological problems will be solved for the next generations of IC technology. For example, Japan is making major investments in commercial synchrotron accelerators that may be either a major technology for future VLSI device fabrication or a costly commercial dead end. If the pace of technological change slows, other nations will have an opportunity to build facilities capable of hitting the slower−moving target of technological advance.

A third, and perhaps most convincing, justification for delaying investment in state−of−the−art process technology is that economies that do not now have major IC production capabilities also lag in electronic systems production. Advanced ICs are a key to producing systems, but making investments in IC production and systems production capabilities are likely to be alternative uses of investment funds. Competition among leading economies is likely to create overcapacity, and therefore low prices, in IC markets. The number and variety of investment opportunities for systems production are likely to be greater during the coming decades, particularly for economies that do not presently have such capabilities.

This analysis suggests a second rule of thumb: *emphasize systems over component production capabilities* . Every nation has different endowments of natural resources, labor skills, manufacturing capability, social infrastructure, and markets for final goods. In addition, many nations have distinct languages, and most have distinctive business practices. Together, this diversity of endowments and technologies offers opportunities for developing electronic systems or information technology products that are specialized to domestic markets. These opportunities range from employing standard hardware to implement specialized software solutions to developing systems products that are more attractive than imported alternatives. Failure of imagination and insufficient domestic technological capabilities are more likely sources of the inability to tap national markets than the superiority of systems products offered in international trade. This strategy matches not only the historical development of the U.S. electronics industry, it also parallels the success of nations that have built major electronic export industries.

The success achieved by Japan, Korea, Taiwan (China), Singapore, and Hong Kong in electronic systems production and export has been based on a steady climb from lower to higher value added electronic products. Once this path is established, backward linkages to appropriate component and subsystems manufacturing capabilities flow naturally from the make or buy decisions of individual firms and their suppliers. The demand for ICs is derived from local and international demand for the use of ICs in systems products. The intense concern of Japanese and U.S. producers about their domestic IC and electronic industry capabilities is likely to make them aggressive IC and electronic systems exporters for the foreseeable future. At the same time, a focus on standardized products and larger markets will leave open many entry possibilities for companies in developing economies to serve their own domestic markets and export specialized products.

The outcome of this process can be satisfactory for both advanced and developing economies. The deployment of essential advanced technologies including IC components, advanced telecommunications switching and telecommunications equipment, and central computer systems can fuel demand for domestic production of consumer products, customer telephone equipment, and data communication terminals. The investment of foreign exchange in the import of advanced equipment will often generate larger market opportunities than its opportunity cost. Comparing this experience with that of other economies that have failed to develop significant electronic export capabilities suggests a third rule of thumb: *import restrictions should be employed sparingly, if at all, to avoid creating technologically laggard domestic monopolies* .

Policymakers in developing economies who have examined the experience of Japan have chosen to emulate Japanese policies of import restrictions without considering the specific role that these restrictions have had in the Japanese industrial development. Japanese companies have been willing to purchase advanced capital goods and license foreign technology when they expand domestic capabilities. Import restrictions are employed when Japanese domestic industry begins to have a realistic prospect of international competitive success. Even then, protection is not a guarantee of success. Despite the tens of billions of yen invested in the Japanese mainframe computer industry, its profitability is only modest. In an era of reduced import restrictions, Japanese personal computers have been successful and profitable in Japan, although only moderately successful in other parts of the world. Broad import restrictions are as likely to hinder development of domestic technological capabilities as they are to fuel their development.

The last rule of thumb relates directly to the contest between standard and application specific ICs. At the present time, the division of future IC demand between standard and application specific ICs is unknown. The reason is simple; no one knows how to fully employ the technological capabilities offered by the current complexity of VLSI devices, nor can reliable predictions be made about the application of the more complex devices that will be produced during the 1990s. It is, however, possible to conclude that the circuit complexity offered by such IC devices will provide a broad set of opportunities for the design of new systems products. It is less obvious, but equally true, that these advanced products will allow far greater flexibility for systems designers in designing both simple and complex electronic or electro−mechanical products. For example, the fall in the cost of monitoring and controlling electro−mechanical systems makes it less necessary to design such systems with high (and expensive to achieve) manufacturing tolerances. Nor is there any reason to suppose that these complex monitoring and control IC products will be expensive or difficult to employ. The forces of international competition that make entry into state−of−the−art IC production a daunting challenge will fuel the creation of new applications by reducing costs and enhancing capabilities (including ease of use). Nations that set out to develop indigenous electronics capabilities, that avoid the pitfalls of excessive protectionism, and that succeed in climbing from low to higher value added products will be well positioned to adopt a final rule of thumb: *employ standard products for cost saving and utilize application specific products to achieve a unique domestic and international position in systems product markets* .

Opportunities for opening new markets and establishing a unique position by employing application−specific ICs may disappear if standard products are able to encompass the diversity of systems design opportunities. Even if this occurs, nations and companies that have thought through the design of successful systems products using application specific ICs will be well positioned to employ standard ICs to maintain a competitive position. If, as suspected, IC and systems product specialization continue to grow rapidly over the next decade, a diversity of systems designs, smaller−scale IC production, and national diversity in electronic systems products will coexist with the standardized equipment and components broadly available in international trade. In short, the world seems to be becoming one in which specialists and generalists will be able to coexist successfully and find ever−increasing trade opportunities.

Notes

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1. The technological history of the IC industry has never been adequately documented and is far beyond the

scope of this chapter. The early history of the industry is documented in Hans Queisser, *The Conquest of the Microchip* , (Cambridge, Mass.: Harvard University Press, 1988), (trans. Diane Crawford−Burkhardt), and Ernest Braun and Stuart MacDonald, *Revolution in Miniature* (2nd edition), (Cambridge, U.K.: Cambridge University Press, 1982). An important source document for examining the early history of the technology is the December 1964 issue of the *Proceedings of the IEEE* .

2. See Nathan Rosenberg and W. Edward Steinmueller, "Why Are Americans Such Poor Imitators," *American Economic Review* 78(2), March 1988, pp. 229−34.

3. Of course, other determinants of varying returns, such as managerial expertise, local market power, or economies of scale, may also be important.

4. See David C. Mowery and W. Edward Steinmueller, "Government Policy and Microelectronics Industry Development: The U.S.," The Center for Economic Policy Research, Working Paper Series, Stanford University.

5. A key event in setting this pattern was the 1956 consent decree that settled the antitrust complaint against AT&T by forcing it to license its transistor patents. AT&T's exchange of technology (which it was barred from exclusively controlling) for cross−licenses with other firms set a pattern of cross−licensing that has persisted to the present. See W. Edward Steinmueller, "Industry Structure and Government Policies in the U.S. and Japanese Integrated−Circuit Industries" in John B. Shoven, *Government Policy toward Industry in the USA and Japan* , Chapter 12 (Cambridge, U.K.: Cambridge University Press, 1988).

6. W. Edward Steinmueller, "International Joint Ventures in the Integrated Circuit Industry" in David C. Mowery (ed.), *International Collaborative Ventures* , Chapter 4 (Cambridge: Ballinger Press, 1988).

7. W. Edward Steinmueller, "Industry Structure and Government Policies in the U.S. and Japanese Integrated−Circuit Industries" in John B. Shoven, *Government Policy toward Industry in the USA and Japan* , Chapter 12 (Cambridge, U.K.: Cambridge University Press, 1988).

8. For a detailed account of the effort, see Daniel I. Okimoto, Takuo Sugano, and Franklin B. Weinstein, *Competitive Edge: The Semiconductor Industry in the U.S. and Japan* (Stanford, Calif.: Stanford University Press, 1984) and W. Edward Steinmueller, "Industry Structure and Government Policies in the U.S. and Japanese Integrated−Circuit Industries" in John B. Shoven, *Government Policy toward Industry in the USA and Japan* , Chapter 12 (Cambridge, U.K.: Cambridge University Press, 1988).

9. See Nathan Rosenberg and W. Edward Steinmueller, "Why Are Americans Such Poor Imitators," *American Economic Review* 78(2), March 1988, pp. 229−34.

10. Congressional Budget Office, *The Benefits and Risks of Federal Funding for SEMATECH* (Washington, D.C.: U.S. Congress, September 1987), p. 81. Intel has announced the technological successor to the 80386, the 80486. The author is indebted to Philip Webre for this source.

11. W. Edward Steinmueller, "International Joint Ventures in the Integrated Circuit Industry" in David C. Mowery (ed.), *International Collaborative Ventures* , Chapter 4 (Cambridge: Ballinger Press, 1988).

12. In addition to these internal resources, the Japanese government has organized and financed a series of successful cooperative research efforts in process technology beginning with the famous very large scale intergrated circuit (VLSI) Program of the 1970s. See W. Edward Steinmueller, "Industry Structure and Government Policies in the U.S. and Japanese Integrated−Circuit Industries" in John B. Shoven, *Government Policy toward Industry in the USA and Japan* , Chapter 12 (Cambridge, U.K.: Cambridge University Press, 1988), and Daniel I. Okimoto, Takuo Sugano, and Franklin B. Weinstein, *Competitive Edge: The Semiconductor Industry in the U.S. and Japan* (Stanford, Calif.: Stanford University Press, 1984), for further information about these programs.

13. See William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 3−6.

14. See William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 2−2 and 2−28.

15. See William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 3−6.

16. See William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 3−6.

17. Computed from figures in William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 3−6.

18. See William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 3−6.

19. Recently, it appears that this effort has become the primary, rather than the secondary, method for attaining SEMATECH's goals.

20. This development, rather than the cooperative research among competing companies, is the more likely application of the antitrust exemption offered SEMATECH under the Research Cooperatives Act.

21. Some have suggested that the solution to this problem is vertical integration of U.S. IC and electronic systems companies. See Charles H. Ferguson, "From the People Who Brought You Voodoo Economics," *Harvard Business Review* , May−June 1988, pp. 55−62. While this may make U.S. IC producers look like Japanese companies, past experience with vertical integration in the United States has been dismal, with the possible exception of IBM.

22. Andrew Pollack, "Big Chill on Asian Chips in U.S.," *New York Times* , September 6, 1988, p. 20.

23. For 1978, see Nomura Research Institute, The *Microchip Revolution in Japan* (Tokyo: Nomura Research Institute, January 7,1980). For 1988, see William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 1−19. Growth is overstated because of the increase in the value of the yen during the past decade.

24. See William J. McClean, *Status 1989: A Report on the Integrated Circuit Industry* (Scottsdale, Ariz.: Integrated Circuit Engineering Inc., 1989), pp. 1−19.

25. W. Edward Steinmueller, *Microeconomics and Microelectronics: Economic Studies of the Integrated Circuit Industry* , Ph.D. Dissertation, Department of Economics, Stanford University, 1987, provides a detailed analysis of productivity improvements resulting from yield improvement in the IC industry.

26. The use of "learning" here mixes the application of additional resources for process improvement in high−volume production with the more traditional meaning of learning: accumulation of knowledge through experience.

27. Texas Instruments and IBM produce significant quantities of DRAMs in their Japanese facilities. One U.S. company, Micron, has specialized in DRAM production throughout the entire period. Micron's ability to compete, at least in current products, raises questions about whether U.S. IC companies have abandoned DRAM production to focus on other products.

28. For design of a particular system, ASICs may be either an economic substitute for the other types of ICs or an economic complement. For example, an ASIC−based design may use memory, but not a microprocessor, or it may dispense with both types of ICs by incorporating the function of these ICs in its own circuitry.

29. See Carver Mead and Lynn Conway, *Introduction to VLSI Systems* (Reading, Mass.: Addison−Wesley Publishing Co., 1980).

30. The discussion in this section is an abridged version of Section III.2. of David C. Mowery and W. Edward Steinmueller, *Participation of Developing Nations in the Global Integrated Circuit Industry: The Experience of the U.S., Japan and the NIEs* , Center for Economic Policy Research, Stanford University, January 1991.

31. L. E. Westphal, L. Kim, and C. J. Dahlman, "Reflections on the Republic of Korea's Acquisition of Technological Capability," in N. Rosenberg and C. Frischtak, eds., *International Technology Transfer* (New York: Praeger, 1985), p. 185.

32. L. Kim, "Korea's National System for Industrial Innovation," unpublished manuscript, 1990, p. 5. The unusually large shares of capital goods in Korean imports during the industrialization period are another indicator of the extensive reliance by Korean firms on "embodied" flows of technology. Kim notes that "Among NICs, the

proportion of capital goods imports to total technology transfer was highest in Korea . . . ," p. 6.

33. See L. E. Westphal, L. Kim, and C. J. Dahlman, "Reflections on the Republic of Korea's Acquisition of Technological Capability," in N. Rosenberg and C. Frischtak, eds., *International Technology Transfer* (New York: Praeger, 1985), who note that "DFI has been a particularly important vehicle for technological development in the establishment of much of the chemicals sector and, more recently, of major elements of the electrical and nonelectrical machinery sectors" (p. 186), and conclude that ". . . the shift to new industries may imply greater dependence on direct foreign investment. Indeed, greater dependence on such proprietary transfers of technology is observed starting in the latter half of the 1970s" (p. 215).

34. ". . . liberalization [in the 1980s] raised the share of Korea's 999 industrial subsectors open to foreign investment from 44 percent in the 1970s to 66 percent in 1984 and to almost 90 percent in 1988." See L. Kim, "Korea's National System for Industrial Innovation," unpublished manuscript, 1990, p. 18.

35. Mody notes that in Korea, "Particular sectors and firms had preferential access to working capital and were charged lower interest rates . . . . Until the early 1980s the cost of borrowing was lower for heavy industry and for large firms" (p. 10). (ref. to 1989 paper).

36. L. Kim, "Korea's National System for Industrial Innovation," unpublished manuscript, 1990, argues that ". . . most important of all [for Korean entry into microelectronics components], there were a number of distressed small semiconductor companies in the U.S. that were ready to sell what Korea's *chaebols* needed most—chip designs and processes—in attempts to fuel cash for survival. Samsung Semiconductor's 64K DRAM . . . technology was licensed from Boise, Idaho−based Micron Technologies, enabling Samsung to hit the market with 64K DRAM some 18 months after the first Japanese ones became commercially available . . . . In short, *chaebols* relied mainly on foreign firms for design and process technologies."

37. See T. Scitovsky, "Economic Development in Taiwan and South Korea, 1965−81," in L. J. Lau, ed., *Models of Development* (San Francisco: ICS Press, 1985).

38. Many of the recent arguments about the competitive weaknesses resulting from the allegedly excessive fragmentation and small firm size in the U.S. semiconductor components industry's competitive struggles with Japanese firms are echoed in this debate over the relative merits of the approaches of Korea and Taiwan (China) to the electronics industry.

39. On the performance of these firms, see M. Jensen, "The Eclipse of the Public Corporation," *Harvard Business Review* , 1989, or the concluding chapter of A.D. Chandler, Jr., *Scale and Scope* (Cambridge, Mass.: Harvard University Press, 1990).

40. As T. N. Srinavasan has argued in his comparison of Korean and Indian economic development, "The lesson is *not* that the Korean government success is because the Korean government did not intervene in markets while those of China and India did. It is that the interventions in the Korean case did not distort incentives as much as those in India did." T. N. Srinavasan, "External Sector in Development: China and India, 1950−89," *American Economic Review* , May 1990, p. 116.

41. ". . . more than 90 percent of firms in Taiwan are small and medium−sized in scale. Therefore, when conducting in−service training, these firms usually encountered problems such as a lack of instructors, insufficient teaching materials, and inadequate facilities. To solve this problem, the government set up two programs to assist these firms. First, it established public training institutes for the electronics industry's entry and middle level manpower. The training courses provided included maintenance of consumer electronics products for maintenance workers, industrial electronics engineering for technicians, and programming skills for CA/CNC programmers, etc. . . . .

"The second program was implemented by the government to meet its ambitious computerization

project. It entails the vigorous education of higher level manpower in the field of computers." G. San, "The Status and an Evaluation of the Electronics Industry in Tai−wan," Organization for Economic Cooperation and Development (OECD) Development Center, May 1989, p. 29.

42. "ERSO is recognised as a good intermediary for technology transfers, since firms occasionally find it difficult to obtain licences. Tatung, for example, wanted to produce 30−megabyte hard disks, but failed to find a U.S. or Japanese firm willing to licence it the necessary technology. As a result, it was forced to develop its own technology and was able to call upon ERSO for help." J. R. Chaponniere and M. Fouquin, "Technological Change and the Electronics Sector: Perspectives and Policy Options for Taiwan," OECD Development Center, May 1989, p. 35.

43. "In several sectors, a government research laboratory, on behalf of or in conjunction with one or several local companies, attempted to 'localise' foreign products based on technology new to Korea. This involved reverse engineering, the employment of Koreans trained overseas in foreign companies, and other methods." M. D. H. Bloom, "Technological Change and the Electronics Sector: Perspectives and Policy Options for the Republic of Korea," OECD Development Center, May 1989, p. 21.

44. ". . . work on the next generation of chips—the 4M DRAM—meant exploring the frontiers of semiconductor technology but also competing neck−and−neck with Japanese and U.S. companies. As the stakes have risen in the chip game, the field of players has grown smaller worldwide, meaning that few, if any, of those left in the game can be counted on to sell state−of−the−art chip design technology to Korean *chaebols* . So, Koreans had to tackle the 4M DRAM design alone. To avoid duplicate research and investment, the government stepped in and designated the R&D of the 4M DRAM as a national project. A public R&D institute played the coordinating role with three *chaebols* ' participation." L. Kim, "Korea's National System for Industrial Innovation," unpublished manuscript, 1990, pp. 35−36.

45. "Several things stand out in the Republic of Korea's pattern of technological development. One is the limited extent of reliance on proprietary transfers of technology by means of direct foreign investment and licensing agreements. Among formal transfers of technology, turnkey plants and machinery imports have played by far the greater role. Moreover, in only a few sectors, such as electronics, have exports depended crucially on transactions between related affiliates of multinational corporations or on other forms of international subcontracting." L. E. Westphal, L. Kim, and C. J. Dahlman, "Reflections on the Republic of Korea's Acquisition of Technological Capability," in N. Rosenberg and C. Frischtak, eds., *International Technology Transfer* (New York: Praeger, 1985), pp. 213−14.

46. For a discussion of this possibility, see D. C. Mowery and N. Rosenberg, "The U.S. National System of Innovation," unpublished manuscript, 1990.

47. ". . . although semiconductors represent the technological heart of IT, it is tempting—but highly misleading—to think of semiconductors as the cornerstone of industrialisation strategies for electronics. In financial terms, the semiconductor (SC) industry represents only a small proportion (less than 10%) of the IT industry worldwide. The SC industry is fiercely competitive and the financial and technological barriers to entry are formidable . . . . As a result, most economies enter IT production through the application of SC to electronic and electromechanical products, rather than the manufacture of SCs." M. Hobday, "Semiconductor Technology and the Newly Industrialising Countries: The Diffusion of ASICs (Application Specific Integrated Circuits)," unpublished manuscript, 1989, p. 1.

48. See M. Hobday, "The European Semiconductor Industry: Resurgence and Rationalization," *Journal of Common Market Studies* 28, 1989, pp. 155−86. It is too early to assess the ultimate effectiveness of the costly trans−European cooperative ventures that are intended to strengthen the presence of European firms in high−volume components, although recent events suggest that this strategy may prove to be difficult.

49. "Because so much of the finished IT system can now be embodied in ASICs, users may find that specifying a systems design becomes synonymous with specifying an ASIC design. In order to remain competitive in systems the user may have to engage in IC design." M. Hobday, "Semiconductor Technology and the Newly Industrialising Countries: The Diffusion of ASICs (Application Specific Integrated Circuits)," unpublished manuscript, 1989, p. 18.

11—
Trends in Worldwide Sourcing in the Electronics Industry

Cary Kimmel

This chapter will analyze perceived trends in the sourcing of electronic subsystems, especially in the office systems business, and will consider the economic and strategic implications of these trends. The information presented here is drawn primarily from the efforts of the Electronic Division of Xerox Corporation to source and produce electronics for a wide array of office system equipment. This unit's experiences are representative of the electronics industry—especially advanced technology consumer electronics and industrial electronics—and of course office systems products. Other industry data have also been included to provide both additional background material and a broader view of developments that are having an impact on strategies for sourcing electronics:

Critical success factors for manufacturers of electronic subsystems, especially as viewed by system assemblers, and how these factors relate to final source selection.

The definition of a universal product cost structure and the impact of this structure on sourcing decisions.

Sourcing as part of a global strategy for multinational operations.

Changes in source selection during the past 10 years.

A model supplier of electronic subsystems.

The design and manufacture of worldwide electronics, which represent a wide array of business segments and which are growing rapidly, have been estimated to be worth in excess of $1.5 to $2.0 trillion. Furthermore, the distribution of production and design capabilities for this industry is global in nature. Although some of these capabilities are concentrated today—especially in the United States, Western Europe, and East Asia—few logistic or economic reasons exist for limiting the entry of new regions into this industrial arena. This industry is essentially a knowledge−based one, in that the supporting natural resource that it requires is technically trained personnel, but also capital for R&D, other equipment, and plant. Communications technology has been said to have turned the world into a global village; electronics design and manufacturing can turn us into a global village economy.

Critical Success Factors: Traditional Approach

One of the key relationships in electronics design and manufacture is the relationship between supplier and vendor. This relationship is extremely complex in this industry, since suppliers become customers and buyers become suppliers, often concurrently. While some vertical integration exists, the speed with which technologies change and the wide array of required technologies inhibit complete vertical integration by most industrial operations. Therefore, the definition, management, and implementation of source selection methodologies and strategies have been, and will continue to be, a major issue for the electronics industry.

Traditional source selection has been based on the availability of a supplier to meet performance goals in the areas of quality, cost, and delivery (QCD). Quality has typically been based on the failure level of the product at both the customer's assembly operation and at the final end user site. Metrics such as defects per million parts, were commonly used for reporting the performance of supplier quality, although operation−based metrics, like mean time between failure, have been common. Cost was, and has been, generally determined by price per part, although additional factors, such as design cost, capital costs, and service expenses have also been considered in the evaluation of this factor. Delivery performance was measured by the lead time for orders, design and production technology, and design capabilities.

The relative importance of each sourcing goal (QCD) was highly dependent on the perceived critical factors for success for the end product. For example, the market demand for consumer products is typically price sensitive. Since price is a critical factor for success for these types of products, supplier selection would most likely reflect a higher weighting for cost than quality or delivery. Another example would be personal, or low−end copiers, where product success is heavily influenced by price. On the other hand, for such products as large, departmental copiers and printers, quality (reliability) becomes a significant factor. In such cases, the lowest−cost supplier may not necessarily be selected. For products that introduce new technology, especially to a mass market (consumer electronics), time to market (delivery) is a major consideration.

In each market, and for each product, however, the factors of quality, cost, and delivery will move to a point of equilibrium, as illustrated in Figure 11.1. That is, competitive and market pressures will drive each product type to achieve a balance between each source selection factor and will thus define the critical success factors for each product. Therefore, source selecting criteria have traditionally reflected a constantly changing series of objectives, that is, ever lower cost, increasingly better quality, and faster delivery times with better technology and product features. Realistically, there must be a limit to this trend. A point of diminishing returns must be achieved, or additional criteria must be developed to help define and structure the market. In the remainder of this chapter, these new critical success factors will be defined.

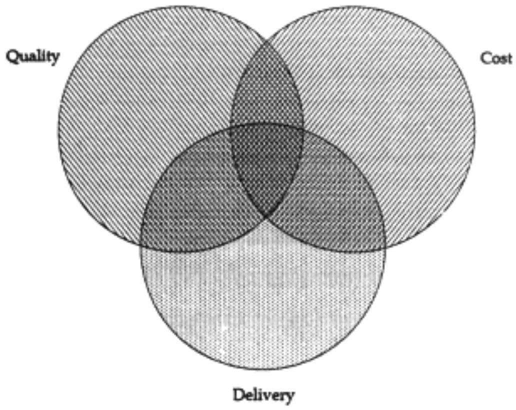

Figure 11.1
Traditional Source Selection

Product Cost Structure—A Nontraditional View

A product's cost structure has played a major role in sourcing decisions, particularly when cost has been identified as the critical success factor. Traditionally, comparative cost analysis, including that used in source selection criteria, has focused on standard accounting methodology. Comparisons were made on labor rates, overheads, margins, and so forth. While such criteria were, and to a degree remain, effective for accounting for internal cost management and control, they fall short of providing a good comparative base for source selection. The main reason for this shortfall are the various means at a plant management's disposal to achieve QCD equilibrium. Tradeoffs between labor, capital, and cost accounting methodology used in a facility all have made comparisons between traditional cost elements difficult and usually misleading. (For example, how does one compare the overhead structure of a fully automated facility with one that still uses a significant amount of hand labor—especially when both are capable of manufacturing the same product?) This is especially true in electronics where a constant change in product mix and technologies would make cost factor assumptions obsolete rapidly. As a means of introducing simplicity to the cost evaluation process, a new, simpler cost accounting methodology has been developed.

This new methodology centers around two basic cost elements, reflecting either the cost of goods and services purchased for the production of an end product—this is called the cost of materials—or the cost of the value added by the assembly facility to an end product—which is referred to as the cost of conversion. Figure 11.2 indicates the relative size of a typical electronic product's major cost components, material, and conversion, as evaluated in 1980, for ex works (at the manufacturing plant) costs.

Conversion costs normally represented approximately 40 percent of the total cost of the product, while materials represented about 60 percent. The trend through the 1980s and into the 1990s has been toward even greater percentages of cost of material—finding some subsystems now with cost

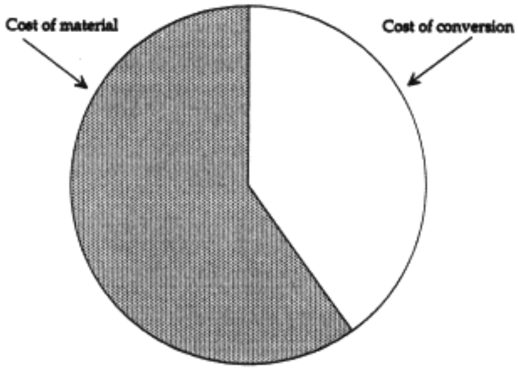

Figure 11.2
Product Cost Structure: A Nontraditional View

of material ratios exceeding 90 percent is not unusual.

Product Cost Reductions—Industry Response

In order to achieve a lower total product cost, many companies have used traditional methods of cost accounting to restructure and analyze their manufacturing of sourcing alternatives. Usually, this has resulted in a focused effort to reduce the conversion cost, although less intensive efforts were directed at the cost of material. The primary reason for this predilection is twofold. First, elements contributing to cost of conversion appear to be completely under the control of operational management. Second, most electronics design and manufacturing facilities had easily identifiable shortfalls in these areas.

This analysis of conversion cost resulted in the identification of two principle cost drivers: location of production facilities (that is, where the assembly facility was located) and labor content intensity (that is, how much labor was involved in the manufacture of the product). In many cases, however, the concept of cost of conversion was not fully carried out, since location cost was primarily evaluated in terms of hourly wage rates and benefits. Therefore, many U.S. companies concluded that they needed to move entire assembly operations offshore to obtain competitive advantage. Some companies worked out the cost of conversion by focusing on reducing labor intensity by designing products for assembly and by investing in automated processes. Other companies decided to off−load subassembly activities partially — especially those that appeared to be labor−intensive—while introducing improved processes to remaining productions. A final alternative was the closure of some production facilities in favor of using contract manufacturing facilities located in areas of low labor cost.

The majority of electronics manufacturers did not focus on the chief cost contributor, that is, material costs, except in the most perfunctory manner. Cost containment for materials often meant negotiating with materials vendors to achieve the lowest possible cost, or looking for cheaper, alternative sources of supply. While these actions could achieve some short−term improvement in material cost, the long−term impact on technology availability or future product joint development (often referred to as partnering or joint venture activity) was serious.

Product Cost Reductions—Xerox Response

At Xerox, once the cost of conversion analysis was completed through competitive benchmarking activities, major efforts were undertaken to reduce the assembly time through product redesign, or in the case of new products, emphasis on time−to−assembly factors. While some off−load was undertaken, it was believed that the need to improve quality and "delivery Critical success factors" made the wholesale redistribution of production capabilities an unworkable Solution. The results of this effort are shown in Figure 11.3. The change in assembly labor time requirements from a second−generation to a third−generation work station product is shown.

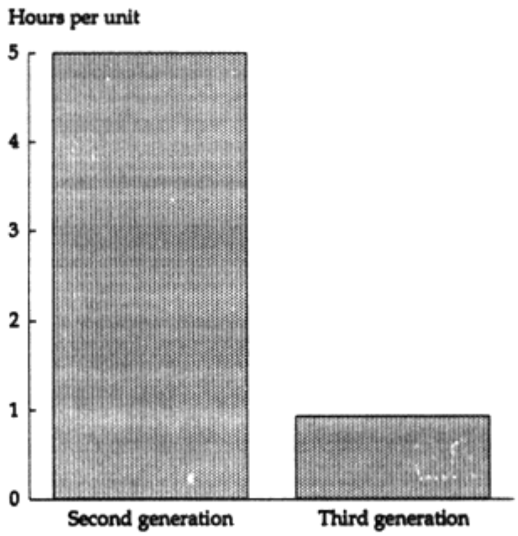

Figure 11.3
Assembly Hours per Unit, Xerox

In this case, the assembly hours for the third−generation work station (6085) were 80 percent lower than the second−generation product (80110). In this instance, there was a more capable product at a reduced cost of conversion. This kind of labor reduction was driven by the understanding that the cost of conversion must be reduced in existing facilities in order to remain competitive.

Changes in product design, simplification of manufacturing processes, and implementation of automation have had a major impact on reducing product cost and in radically reshaping the product cost structure itself. As a result of these changes, the conversion cost is no longer or should no longer be, a significant factor in source selection. Furthermore, since labor cost is a major element in the cost of conversion, and the cost of conversion has been so reduced, labor cost can and should no longer be considered a major element in source selection criteria. Conversion cost has decreased as a percentage of product cost from 40 percent to less than 20 percent in a period of seven years as a result of aggressive cost control and design activities. This percentage continues to decline (Figure 11.4).

Direct labor costs are now less than 10 percent of total product cost, and the percentage continues to decline. This reduction occurred at the same time that Xerox had taken significant steps to reduce and manage component costs. (In 1986 Xerox was cited by *Purchasing* magazine for the excellence of its procurement program.) The rate of reduction in cost of conversion was significantly greater than the rate of reduction in the cost of material. Furthermore, during the same period, the level of customer−perceived quality of Xerox products improved markedly, although there was a significant reduction in the quality of electronic subsystem manufacturing, and Xerox continued to remain a leader in introducing new technology to the market.

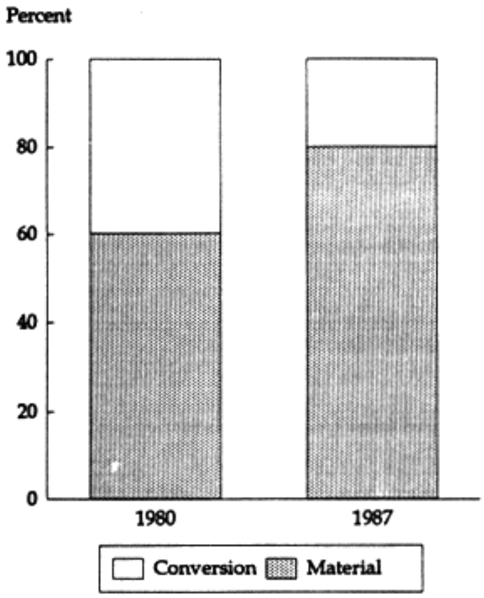

Figure 11.4
Changes in Cost Structure Composition
from 1980 to 1987, Xerox

Although this chapter has tended to downplay the results of the efforts regarding cost of material during this period, significant efforts were made to reduce costs. Specifically, two complementary actions were taken simultaneously:

First, the traditional approach to cost reduction was taken with components and subsystems that were not viewed as conducive to major technological leaps. Actions in this area include (a) consolidations of ordering activities to a smaller number of qualified vendors' efforts in order to improve delivered quality (and thereby reduce overhead costs of materials handling) to Xerox and (b) earlier involvement of vendors in development programs to assure component availability and faster vendor−initiated quality enhancement activities.

Second, in those areas where technological leaps were expected, partnering with selected companies was encouraged.

The results of these activities have controlled the nonproduct−, nontechnology−driven increases in the cost of material, while assuring an increasing functionality of Xerox products.

As a final point, regardless of the actions to control and eliminate unnecessary factors contributing to cost of material, future trends are clearly indicated in Figure 11.4. The continuing trends in process automation, as well as increasing complexity and capabilities of integrated circuits, will lead in the 1990s to a cost structure for high−end electronics of 95 percent cost of material and 5 percent cost of conversion.

Logistics Costs—The Hidden Costs of Conversion

Companies that pursued offshore sourcing discovered that logistics costs relative to sourcing began to increase, adding even more pressure to develop new approaches to source selection. Logistics costs applies to all incremental cost associated with dealing with suppliers far from the initial site of design and final assembly site. These costs include items such as duty, freight, communications, special handling and administration. Depending on the location of the supplier, the complexity of the design, and the sophistication of the manufacturing site, these costs can be considerable. Figure 11.5 shows a typical landed cost structure for an electronic assembly sourced from the Far East. As indicated in this figure, it is not unusual for logistics costs to be as high as the conversion cost. Therefore, the decision to source from a remote supplier to obtain cost benefits because of lower wage rates has to be carefully evaluated in light of incremental logistics costs—hidden costs that can inflate the landed cost of imported electronic products.

Summation—Product Cost Structure as the Driving Critical Factor

The economic factors that drove many U.S. and European electronics companies to consider and implement massive off−shore manufacturing were primarily related to labor costs and labor utilization. However, as a result of decreasing labor content, wage rates are no longer viewed as a significant factor in sourcing decisions where cost is a critical success factor. Furthermore, increasing costs, as a percentage of the total product cost of remote manufacture, especially for custom design and smaller production runs, has introduced new economics into the equation for source selection.

The New Critical Success Factors

Companies are focusing their efforts on reducing those elements that contribute to the cost of material. Furthermore, many, like Xerox, are looking for suppliers who have knowledge of emerging materials technology and processes, and who also have access to low−cost sources. In other words, cost reductions (regardless of source) are one part of this drive to achieve QCD equilibrium. New sources are being introduced into the source−selecting process based not only on manufacturing capabilities, but also on technological capabilities.

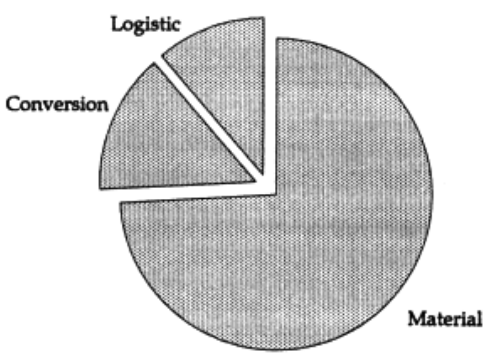

Figure 11.5
Landed Product Cost for an Electronic
Assembly Sourced from the Far East

In addition to these changes in produce cost structure and supplier selection criteria, additional new factors are influencing supplier selection. These factors reflect the new realities in the electronics industry (see Figure 11.6). First, product life cycles are becoming increasingly shorter. Twenty years ago, companies had products that survived for 10 years in the market. In today's market, a product life of three or four years is optimistic. Companies are looking for suppliers who provide assistance in reducing the time required to launch new products (time to market) and who are able to rapidly respond to changes in the marketplace. The major perceived and universally discussed critical success factor of the 1990s is time to market. Realistically, what took 36 months to develop in the early 1980s has to be developed in 18 months in the 1990s.

Second, to maximize demand and profitability, products are being marketed on a worldwide basis. The global village economy has tended to erase national frontiers. Suppliers with market presence in new areas enable their customers to be more successful with global marketing efforts.

As a result of shorter product cycles, the need for global markets, and the requirement to continue cost reduction activities, customers and suppliers out of necessity have been more closely drawn together. This has led to a need to reexamine the adequacy of QCD as the only factors for determining sourcing strategy. As previously discussed, in the past a model supplier was one who

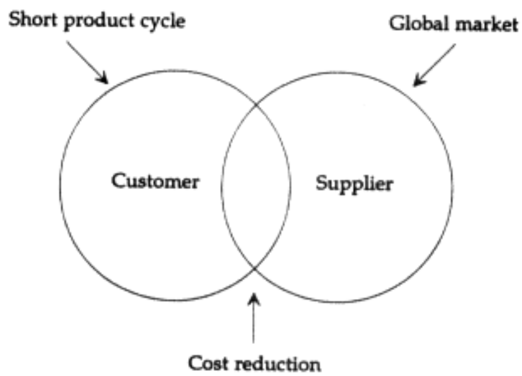

Figure 11.6
Factors Influencing Supplier Selection

was able to meet established performance goals for QCD. In today's world, this is no longer adequate. In addition to the traditional QCD, companies are looking for suppliers who can provide technology CO and service (S).

In the area of electronics manufacturing technology, for example, the model supplier can provide a complete interconnect packaging capability, including everything from semicustom chip to system integration. The new model supplier must be able to interact comfortably with the customer's design team, adding value to the relationship earlier in the product design cycle. Early vendor involvement has become a necessity, not just a buzz word.

Supplier knowledge of emerging materials and manufacturing processes is becoming linked to the customer's ability to reduce product cost. In electronics subsystem manufacturing, a model supplier must have a working knowledge of new processes that are not labor−intensive, but which ensure that objectives of quality are achieved. Technologies and processes once viewed as leading edge, which must now be considered the norm, include the following:

Surface mount

Small outline integrated circuit

Plastic chip carrier

Pin grid array

Tape automated bond

A model supplier should have the appropriate computer−aided design (CAD) or computer−aided manufacturing (CAM) capabilities in−house, have the appropriate level of automation and robotics required to support new technology, and be able to ensure rapid conversion of customer specifications into product. The ability to process customer requirements successfully and quickly assures a smaller impact from logistics cost and quicker time to market.

In the area of service, the model supplier would be expected to provide a full range of engineering services, both complementary and supplementary to those employed by the customer. These services include the following:

Design services

Test engineering and equipment design

Component qualification

Failure analysis

Valued analysis/value engineering (VA/VE)

Prototyping

The supplier's procurement and marketing capabilities are becoming increasingly important. Buying power and access to local markets are of major significance, especially in times of component shortage and multinational marketing. Electronic communication capabilities, especially broadband access, are also becoming more important in expediting everything from order fulfillment to transfer of design changes. Again, this capability has a positive impact on logistics costs and time to market.

New Critical Success Factors—A Xerox View

The criteria used by Xerox to select suppliers of disk drive subsystems provide insight into the way customers are evaluating suppliers in today's environment and are applying these new critical success factors to supplier−selection processes. The objective of Xerox's sourcing strategy for disk drives was to encourage early introduction into Xerox's products of high−quality, cost−effective leading−edge technology, while encouraging the use of commodities that meet industry standards in its wide range of products.

The sourcing decision of disk drives was based on an evaluation of a supplier's ability to meet the following requirements:

Quality: A company with a dedication to quality through processes, statistical measurements, and management commitment.

Cost: A company that is competitive in total pricing and cost of ownership, as measured by industry benchmarks.

Delivery: A company that can meet all quantity requirements and that can adapt to technological as well as volume changes.

Technology: A company with adequate staff and capital to ensure that it remains current in the science and application of the product provided and not just the application of current technology to a volume production shop. A factory that builds with modern techniques.

Service: A company with an established plan for improvement through product redesign and that is willing to share market trends and technology breakthroughs on a regular co−exchange basis. A company with a sound presence in the marketplace and in customer support facilities.

As indicated in these requirements, factors related to service and technology (S&T) were an integral part of the sourcing strategy. The new factors redefine the relationship from merely a supplier−customer one into more of a partnership. As the need for a closer customer−supplier relationship gets stronger, customers will consolidate their requirements with fewer suppliers, and will maintain these relationships over a long period. The previous standards of selection of supplier—that is, quality and deliverable to specification, and contract to the lowest bidder—will not work in this environment. Figure 11.7 shows how this phenomenon has affected the number of disk drive suppliers to Xerox.

As can be seen in this case, the impact of expanding the supplier selection criteria to include S&T criteria has resulted in a significant decrease in the number of suppliers. The remaining suppliers each meet the supplier criteria for a broad range of products, and each sees Xerox as a major customer, further reinforcing their desire to meet customer requirements. Projecting this particular trend for this commodity into the 1990s could be misleading and certainly would develop incorrect conclusions. The data shown in Figure 11.7 are based on a set of known technologies and applications. As new technologies affect disk drives (or even hybrid or new storage devices), the number of suppliers could increase. This increase, however, could be viewed as temporary, since the same process of definition of customer QCDST (QCD plus service and technology, as discussed above) will come into play.

New Critical Success Factors—An East Asian Response

The primary beneficiary of the initial off−load manufacturing trend in electronics was East Asia. Significant numbers of electronics contract manufacturing facilities were established in Singapore, the Republic of Korea, Taiwan (China), and Hong Kong during the late 1970s and 1980s. Building on their advantage of a disciplined, motivated, and inexpensive labor force, these economies built electronics manufacturing capabilities that are now significant factors in maintaining the health of their export−oriented economies. The ability of the companies in these economies to adapt to the new critical success factors will determine their ability to remain model suppliers.

As part of its ongoing activities to understand and analyze the electronics design and manufacturing environment, the Electronic Division of Xerox takes periodic surveys of market trends, infrastructure development, and capability development on a worldwide basis. These studies are made in an open manner, with the resultant data being shared among the respondents.

The results of a recent survey of nine leading electronics suppliers in East Asia (in Singapore, Hong Kong, Taiwan (China), and Korea) were structured, in part, to determine whether there was a growing understanding of these new success factors. The results clearly indicated that manufacturers in the region are aware that success is becoming more dependent on improving S&T capabilities.

Figure 11.8 shows reported sales activities for all nine companies in the survey by product line.

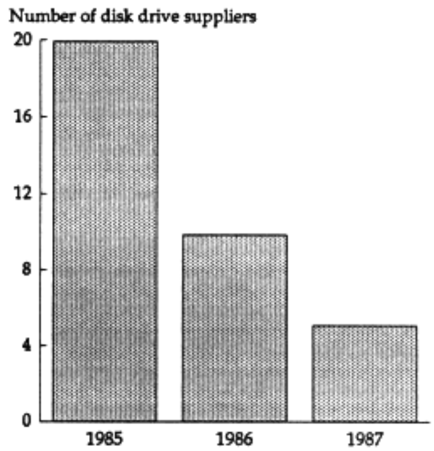

Figure 11.7
Number of Disk Drive Suppliers to Xerox, 1985−87

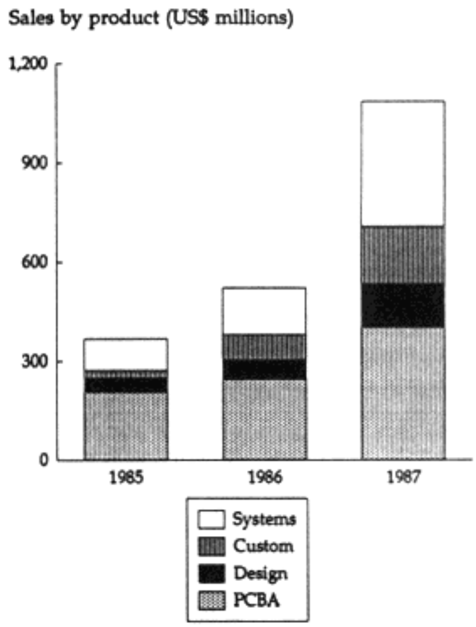

Figure 11.8
Sales by Product Line for Nine Surveyed
Companies in East Asia, 1985−87

Systems, custom, and design all refer to activities that require incremental service and technology support. Printed circuit board assembly (PCBA) in the electronics industry is traditionally sourced from subcontractors.

The overall revenues for the nine companies in the survey grew from slightly less than $400 million in 1985 to over $1 billion by 1987. This revenue is projected to exceed $2 billion by the mid−1990s. In 1985 engineering services, custom and semicustom design, and system integration activities were approximately $100 million. By 1987 these products and services amounted to almost $600 million in revenues and represented most of the growth during this period. The ability to achieve such spectacular growth cannot be attributed to either the low labor costs in these countries, or to the continued high demand for electronic components and subsystems, or even to currency pressures. As previously stated, while projections for an individual company may be difficult, their aggregate revenue will likely exceed $2 billion by the early part of this decade. What is of interest is not the growth itself, but how that growth is and will be attained. The growth is being achieved by continuing the trend to S&T, as previously noted.

Already, several of these companies have established sales subsidiaries in the United States and Europe and have started direct−to−the−customer sales of branded merchandise. Therefore, in the space of less than a decade, these companies have moved from being contract suppliers of labor−intensive subsystems and assembly to fully integrated suppliers of advanced systems. An analysis of growth by company indicates that those that provide S&T have the highest growth rates. If these revenue figures are converted into identification by market segment, dependent on either the older QCD or new QCD + ST success factors (Figure 11.9), the trend is evident.

Furthermore, looking ahead into the 1990s, the true percentage of business generated by QCD critical success factors is actually likely to decline as customers expect greater value−added activities, even from what was at first only activities to offset the cost of labor.

On an individual basis, companies that provide S&T to their customers experienced a growth rate of over 400 percent during the three−year period compared with only 30 percent for the more traditional contract manufacturing companies. It is of more than passing interest that the greatest growth was experienced by those companies located in countries with well−defined national policies that encouraged the growth of S&T capabilities.

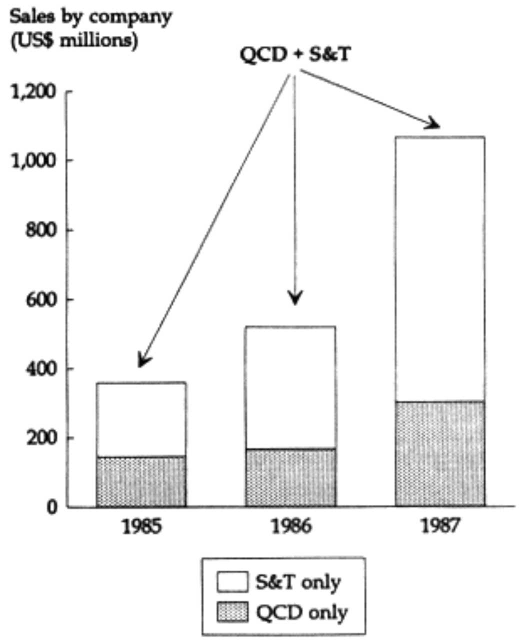

Figure 11.9
Sales by Company for Nine
Surveyed Companies in East Asia

These data clearly imply that supplier growth is no longer simply dependent on the market growth of the customer's product, but is also determined by the spectrum of capabilities that a supplier can provide. It is also evident that the East Asian companies surveyed fully understand the new reality, and are reacting to it.

Implications for New Players

Generalizations regarding an industry the size of the electronics design and manufacturing sector are difficult to make, and finding examples that disprove them is easy. However, the following trends should be considered in establishing either a multinational sourcing strategy or a national industrial strategy for electronics.

Labor cost will continue to contribute a diminishing percentage of overall product costs. The use of labor cost as a primary critical factor by a company would either be an interim measure, or would be used for "trailing−edge" or end−of−life products. The development of a national policy based on low rates of labor would relegate that nation's electronics capabilities to an ever diminishing niche market.

Quality and technology requirements will drive manufacturing away from labor−intensive processes toward capital and knowledge−intensive processes. This will increase the interdependence of customers and suppliers, since neither would be willing to commit either capital or design standards unless a long−term relationship existed. This will also accelerate the trend toward strategic relationships in the design and marketing of joint products.

Produce acquisition cost (that is, design and development) will continue to increase and will play an increasing role in product life cycle costs. Control of these costs, as well as the impetus toward quicker market engagement (that is, time to market) will accelerate the trend toward early vendor−customer relationships. Companies that do not provide design and development capabilities will be relegated to slow growth niches.

Companies that do not use vendors with design and development capabilities will have to maintain premium prices.

While the impact of real currency movements has accelerated the efforts of some Japanese companies to realign electronics manufacturing toward lower cost areas, this is a short−term phenomenon. Japanese manufacturers have been somewhat slower to react to the labor cost issue; slower reaction, in this case, could be viewed as a positive reaction. Even with the Japanese electronics manufacturers, the long−term trend will be toward greater supplier−customer integration in the design and manufacturing phases of product life.

In summary, companies that establish a game plan solely based on traditional QCD strategies will fail, at least in high−technology products. The new critical success factors of both service and technology will continue to become one important variable in the equation. Countries that base their strategy for the electronics industry solely on low−cost labor will not achieve the full benefits or growth from this fast−growing industry.

PART III—
THE NEWLY INDUSTRIALIZED ECONOMIES

12—
Strategic Underpinnings of the Electronics Industry in the Newly Industrialized Economies of Asia

Denis Fred Simon

The rapid emergence of the newly industrialized economies (NIEs) in Asia as important actors in the international electronics industry has sparked the attention of scholars, business leaders, and policymakers.1 Several volumes have already appeared, which assess the implications of the growing presence of the NIEs in microelectronics and computers for the evolving international division of labor.2 Phrases such as "the East Asia edge" have emerged to highlight the dynamic element of NIEs in both economic and technological terms.3 By the early 1980s, for example, approximately one−third of the dollar value of electronics products and components imported into the United States came from Hong Kong, the Republic of Korea, Singapore, and Taiwan (China). By the early 1990s, the locus of electronics trade in North America had already shifted from the Atlantic to the Pacific Rim.4 As a result, in assessing the future structure and character of the global electronics industry, the phenomenon of NIEs has shown that it is not just a passing one. In fact, a recent Japanese commentator noted that "by upgrading their production and trade structures, the Asian NIEs [newly industrialized economies] have emerged as a new 'growth axis' in Asia," and they have transformed Asia's growth structure from a "monoaxis" led by Japan to a "multiple axis" structure.

The phenomenon of the NIEs has been analyzed from several perspectives, but few, if any, of the existing studies have focused primarily on the technological dimensions of their respective development programs.5 Within the context of the electronics industry in the NIEs, the issue of technology is important because these economies are increasing their attention and expenditure on research and development (R&D); they are contributing to a growing concern about technological leveling by potential competitors; and the number of cross−border, technology−based alliances is expanding rapidly.6 The Asian NIEs have been cited as an example of the continued viability of capitalism as a development model for their success in harnessing foreign investment, and for their low−cost, labor−intensive production systems.7 Yet, to understand fully why the NIEs have been able to make such a splash in the international electronics marketplace, and why they have been able to maintain appreciable rates of growth even in times of relative recession in the global economy, the issue of their technological progress and potential cannot be ignored.

This chapter attempts to redress this important gap in the literature on NIEs by looking at the process and problems of development in the electronics industry of the four Asian NIEs. The four NIEs have gradually, but steadily, moved away from being merely low−cost original equipment manufacturer (OEM) manufacturing sites for developed country, transnational corporations to being primary producers selling under their own brand names. Low quality is no longer generally associated with the products and components coming out of these economies. It is precisely the ability of the NIEs to increase appreciably the technological sophistication of their components and final products that has attracted so much attention. Although they possess only modest domestic R&D capabilities and are still major purchasers of advanced technology in the international marketplace, the Asian NIEs are no longer entirely dependent on external sources for their electronics product or process know−how.8 In this regard, a legitimate question to ask is how they have been able to accomplish this feat in such a relatively short period. Another question to ask is how the emergence of these new centers of technological dynamism in such industries as microelectronics is likely to affect that nature of global competition and technological collaboration in the years ahead?9

The argument offered in this chapter in response to these questions is twofold. First, in order to understand the process of electronics development in the Asian NIEs, attention is focused on the role of the state as an initiator and facilitator of programs in research and development, education, and economic and technological restructuring.10 Even though the state has been committed in principle in all four instances to allowing the forces of the market to guide the operation of the economy and the behavior of local firms, it has often found intervention necessary—and at times desirable —where private sector responsiveness was lacking or where the local economy lacked the maturity to compete effectively in the international market. In this regard, the role played by the government within the electronics industries of the respective Asian NIEs has more often been oriented in the direction of market enhancement than market replacement.

The second part of the argument takes the role of the state one step further and argues that the most critical aspect of state behavior vis−à−vis the electronics industry has been in its dealings with transnational corporations on foreign investment and technology transfer. In general, the government in each of these economies has been able to manage the processes of foreign investment and technology transfer in such a way as to maximize the flow of foreign technology and know−how into the local economy. In many cases, the presence of foreign companies—either in terms of equity−based investment, their final product and component sourcing activities, or licensing of technology—has served as an important catalyst; that is, they set off the search for new and more efficient technologies on the part of local firms (public and private). Through the demands of product end users in the market, as well as the backward and forward linkages created by foreign firms, at times as a result of government−imposed domestic content requirements, the technological modernization of the electronics industry was set in motion. As a result of these steadily acquired technological strengths and assets, the Asian NIEs will increasingly be drawn into the dynamics of global competition in the electronics industry, particularly through their increasing involvement in the high−value−added segments of the electronics industry.

Obviously, the process by which electronics development has and still is occurring in each of these four economies has been different.[11] Each has a distinctive economic system, and the nature of business−government relations is also country−specific. These differences, along with the various structural features of the international economy, have imposed certain constraints on the extent and nature of state intervention in the electronics sector. In the case of Hong Kong, the state until recently had pursued a policy of "positive nonintervention," while in Korea direct state intervention has spanned the complete spectrum of that economy's electronics sector. Moreover, comparing such economies as Hong Kong and Singapore with Korea and Taiwan (China) is difficult because of their differences in size, population, political systems, and security concerns. In addition, despite the tendency of many observers to group them together, Taiwan (China) and Korea have diverse industrial structures—with Korea's dominated by 9 or 10 major industrial conglomerates and that of Taiwan (China) dominated by small and medium−size companies. Nonetheless, in spite of the diversity among them, the four economies all share two important features that make it possible to offer generalizations about their behavior and their experience in the electronics sector.

First, their experiences in electronics reflect the importance of state intervention in essentially free market economies, indicating how strong development−oriented economies can induce certain forms of economic behavior, even if, at times, they induce this behavior through artificially−induced market distortions, such as forms of "technological protection." Second, each economy has been faced with the dilemma of how to position itself strategically in global and regional electronics markets and associated industry segments. In each case, promoting the advance of technology has received support and justification from the imperative of achieving competitive advantage in key industries, such as electronics. The economies' respective responses to this challenge, especially in relation to their ability to harness foreign technology successfully, go a long way toward explaining why they have been collectively successful in overcoming their past technological dependence and in growing at such a sustained pace over the last two decades.

The Electronics Strategy of the Asian NIEs

Five main components have made up the NIE strategy for industrial development in general, and five guiding principles have been followed in the

particular case of electronics development. The most critical general factors have been the financial and tax policies designed to encourage firms to adopt new ideas and innovations. In Korea, for example, the role of banks and state−led financial institutions has been highly important. Second, a combination of policy instruments and economic incentives has been introduced to help diffuse existing technology. Various state−sponsored institutions, such as the Industrial Technology Research Institute (ITRI) in Taiwan (China), have been created to ensure that new knowledge and technology spread to relevant end users. Third, a series of related policies have been implemented that are aimed at improving the process of importing and utilizing technology. In Singapore and Taiwan (China), taxes on technology imports have been drastically reduced, and much of the red tape formerly experienced by foreign suppliers and local recipients has gradually disappeared. Similar policies for regulating the activities of foreign firms have also been instituted in order to ensure that the activities of transnational corporations (TNCs) are consistent with overall industrial priorities.

Fourth, each of these economies has made major investments in education and training, especially in the fields of engineering and science. Literacy rates in the four Asian NIEs are among the highest in the developing world, averaging well over 90 percent. The recent establishment of the University of Science and Technology in Hong Kong, for example, reflects the commitment to train a cadre of technical personnel to meet the challenges of the 1990s and beyond. And last, each government has created various vehicles for the collection and dissemination of economic and technical information, so that firms are constantly aware of changes in market situation, foreign government policies, and so forth. Taken together at least at the macro level, these factors underlie the amalgam of technical and economic policies that have supported both export expansion in the late 1960s, industrial deepening in the 1970s, and technological upgrading in the 1980s.

In the case of developing the electronics industry, the five guiding principles have included selectivity, focus, infrastructure, temporal coherence, and linkage. Capital and personnel resources were targeted to meet *selective* or specific, rather than general or ambiguous, objectives in the electronics sector. These resources were drawn from a strong and ever−improving physical and educational *infrastructure* that was the product of government investment and nurturing. Although all four societies experienced some initial problems with "brain drain," over time the problems became less serious. Today, in fact, a "reverse brain drain" is being witnessed, whereby many people who had left in the 1960s and 1970s are now returning to start up new ventures in the electronics and computer sectors. Recognizing that attempting to take on too much would place a great stress on existing resources—financial and human—a decision was made to *focus* rather than scatter these resources on a limited number of projects. This prevented their dilution. Fourth, the strategy of development was a sequential one, where policies and projects adopted in the short term provided maximum flexibility for adaptation and refocusing over the longer term. This type of *temporal coherence* , although the result of a combination of intent and accident, facilitated rather than precluded entry into higher value−added segments of the electronics and informatics industries.

Finally, the electronics strategy of the Asian NIEs has been conspicuous by virtue of its emphasis on development through *linkages* with foreign firms, especially those from the United States. In contrast to Brazil and India, for example, whose approach was characterized by a greater stress on self−reliance, the Asian NIEs understood the need for building alliances and joint ventures, as well as for following those firms more in touch with the market and more experienced than they.

Foreign Investment, Technology Transfer, and Electronics Development in the Asian NIEs

In a discussion of the electronics industry in the Asian NIEs, it may appear strange to start off with a discussion of foreign investment and technology transfer. Yet, in assessing the history of development in each of these economies, one fact stands out above the rest, namely that each of the four Asian NIEs has attached great importance to its links with TNCs. In some cases, as in that of Tai−wan (China), the importance of these links extends into the political arena, providing the island with international legitimation through its participation in a "transnational system" where economic and technology relations with TNCs act as a proxy for formal diplomatic relationships. Putting aside such unique circumstances, however, all four share a common viewpoint in terms of the special importance they attach to the dimension of technology transfer in their relations with transnational companies.[12] And since, up until recently, most of the critical technologies in the electronics industry sought by these four economies has been owned or controlled by major transnationals, it is not surprising to find that their relations with foreign firms, especially in the area of technology, have been steadily growing over the last two decades.

Obviously, the technological push occurring in each of these four economies is a relatively new phenomenon. For most of the postwar period, they have all exhibited a high degree of dependence on foreign technology. The basis for the development of the consumer, components, and computer segments of the electronics industry has been technologies that originally first appeared in the United States or Western Europe and Japan and later, through the playing out of the "product−life cycle," moved to the Asian region as a result of the search for low−cost labor. As suggested earlier, even as the NIEs move into the more advanced stages of microelectronics, such as the design and manufacture of very large−scale integrated circuits (VLSIs), they are still major buyers of technology in the international marketplace. For the most part, they are still a long way off from attaining the technological levels of the United States and Japan. Total R&D spending, while steadily increasing as measured in terms of percentage of gross national product (GNP), is still small in terms of real dollars. Acknowledging this, however, a unique feature has been their ability to reduce, albeit gradually, the predominant position of foreign firms in the most dynamic sector of their economies—a position that frequently has been based on the firm−specific technical capabilities of these foreign electronics companies. More recently, as globalization has proceeded in terms of the dynamics of international competition, these economies have become more attractive as potential partners in various types of collaborative ventures aimed at taking advantage of their accumulated experience and utilizing their manufacturing dexterity or plugging into the pool of well−trained engineers in their R&D institutions.

Of course, not all the electronics technology in the Asian NIEs has come directly from the transnational firm in the form of foreign investment or direct licensing. In Hong Kong, for example, because of the absence of investment or market barriers, there has been little incentive to transfer technology through formal channels. As a result, the "learning−by−doing" phenomenon has been the more common means of acquiring technology. In Taiwan (China) and Korea, much of the early know−how to support primary import substitution programs came from U.S. Agency for International Development (USAID) programs or from foreign military aid. Later on, this know−how became important for attracting foreign electronics firms interested in using local labor for manufacturing electronics components or consumer items.

Differences did exist, however, among the various economies. In the case of Taiwan (China), the degree of dependence on outside sources for electronics technology was generally much greater than in Korea. The forces of nationalism in general, combined with specific concerns about dependence on Japan in particular, led Korea to seek more of an arm's−length relationship with foreign firms, preferring, in comparison with Taiwan (China), to rely more on loans and credits rather than on foreign investment as a means to secure technology. Thus, while foreign investment and subcontracting became important vehicles for technology transfer in the electronics industry of Tai−wan (China), such was not the case in Korea until the 1980s. This is true despite the fact that firms with foreign capital were responsible for 73.1 percent of domestic output for electronics components and for 76 percent of components exports in 1980.[13]

In spite of these differences, however, one factor holds true in all cases, namely, that it was interface with the demands of the global marketplace that gradually provided the impetus for creating or upgrading domestic technical capabilities in the electronics sector.[14] The key to their ability to make effective use of foreign know−how was in the aggressive approach the NIEs adopted in dealing with TNCs.

With respect to the overall development of the electronics industry, various factors have contributed to the availability and effective use of foreign technology in the four Asian NIEs. As Baranson notes, the growing desire for technology within the Asian NIEs occurred at a time when corporate attitudes about technology were changing, a development that gradually strengthened the bargaining position of the purchasers.[15] In addition, the cost−based nature of competition in the consumer electronics side of the industry fostered the shift of production operations out of the United States and Japan. Similar reasons account for the later movement of components and computer−related products, such as hard disk drives. In the case of the recipient firms, growing investments in domestic production and R&D capabilities have gradually made the Asian NIEs better able to identify their technological options and alternatives. Westphal and Dahlman have referred to this as the process of technological accumulation.[16] With expanded knowledge, local firms—public and private—have been able to improve their negotiating position vis−à−vis foreign suppliers.

The experience of the Asian NIEs also emphasizes that successful use of foreign technology depends on an effective set of policies for regulating the inflow of this technology. National controls, combined with an enhanced domestic capability, have greatly improved the terms of technology

transfer. Technology transfer was never an end in itself; technology imports can be said to have had an "economic focus" rather than a "technological focus."

In this regard, and perhaps most critical, the approach to importing technology was conceived as part of a larger strategy for developing electronics. Rather than viewing the acquisition of foreign technology as separate from other related initiatives, economic policymakers within the Asian NIEs attempted to take full advantage of the synergism derived from cooperation with foreign firms in the electronics industry. Development objectives in such areas as employment, trade, and training were all served by closer links with foreign firms, especially where exports were concerned. Whether Singapore, Taiwan (China), or Korea is being discussed, as attempts to move into high stages of the value−added chain in electronics have occurred, these links have increased in importance for both sides. Today, within the electronics sector, it is safe to say that the Asian NIEs have entered into a relationship of overall technological interdependence rather than dependence with the major technology−based firms in the developed world.

A Case Study: The Role of Foreign Technology in Electronics Development in Taiwan (China)

Foreign technology in the electronics industry in Taiwan (China) has played a critical role in the industry's overall development since the 1960s. The leaders of Taiwan (China) have adopted a two−pronged strategy for promoting the development of the electronics industry. One major goal has been to use the process of technological upgrading, as part of a strategy of "technological complementarity," with key electronics companies in the international economy. In many ways, the essence of this policy has been reflected in attempts to increase the "dependence" of transnational firms in Taiwan (China) first as a foreign investment site and later as a source of sophisticated electronics components. Rather than competing head on with firms from the developed economies as has been the case with Korea, Taiwan (China) has adopted a strategy whereby it seeks to manufacture electronics products and components that build upon products designed and offered by developed economy TNCs.17

The other goal has been to increase the island's technological self−sufficiency in electronics, especially in industrial components, through industrial and technological deepening. Policymakers in Tai−wan (China) have been reluctant to allow its domestic electronics industry to be dominated by foreign companies. As a result, this has led the government to increase its efforts at strengthening the island's R&D system, so as to facilitate the development of an assortment of critical production technologies. Interestingly, the achievement of these two objectives—technological complementarity and greater technological self−sufficiency —are to be accomplished primarily through the acquisition and use of foreign technology.

The move of Taiwan (China) into its much her−aided export promotion stage in the late 1960s coincided with the phase−out of the USAID mission and the initial arrival of foreign investment. During the 1950s and early 1960s, uncertainty over the political viability of Taiwan (China) had basically deterred a large flow of foreign investment, except for some from a few small overseas Chinese investors and some from the United States and Japan. By the mid−1960s, perceptions about the longer−term survival of Taiwan (China) began to change. Interest in Taiwan (China) grew slowly because of the infrastructure that was in place and because of a series of investment statutes created to make the island an attractive site for locating a factory, particularly for assembly−type operations where foreign companies could take full advantage of the lower cost−wage structure. In addition, the formation of the Kaohsiung and Nantze export processing zones—each also offering additional investment incentives—further sparked interest.

In most of the initial examples of foreign investment, especially in the export processing zones, little direct technology transfer actually took place. In terms of the electronics industry, most of the projects were in the low−end consumer electronics category, involving simple assembly−type operations performed by many young women. The zones operated like foreign enclaves, minimizing the amount of contact between the local economy and the foreign market, except in terms of the workers who moved in and out of the zones in response to new or better employment opportunities. Over time, however, it was the mobility of the labor force that proved to be one of the main vehicles for technology and skills transfer, especially in terms of middle−level management and technical personnel. A percentage of the individuals who initially were trained to work in the zones for foreign electronics firms went on to start up their own companies or brought their skills into the local economy for application in domestic electronics firms.

As foreign investment began to increase in the mid−1960s and 1970s, so did the number of formal technical cooperation agreements in the electronics sector. Here again, some of the increase was a reflection of the new regulatory regime set up by the government to promote technical cooperation with foreign firms. The specific factors behind the growing interest on the part of foreign firms were twofold. First, in industries such as electronics, foreign firms had to begin doing more local sourcing; helping to upgrade local capabilities also became cost−effective, as well as good business practice. In some circumstances, the government required such assistance as part of the approval process for establishing a foreign−invested factory. Also, the laws concerning capitalization of technology by foreign firms in joint ventures tightened up. This led companies to seek more formal means of obtaining a direct return on their know−how.

Second, rendering such assistance was based on pure economic considerations. The practices of U.S. and Japanese companies differ considerably in this regard. For Japanese firms, technical cooperation became a vehicle for expanding the extent of Japanese vertical integration on the island. Settling for joint ventures in many cases, even with minority ownership, Japanese firms often required a technical cooperation agreement when forming a joint venture in order to create a mechanism of control, as well as to obtain an additional return on their technical know−how. According to one study, these technical cooperation agreements frequently did not really involve much technology transfer. As the study suggested, there was more evidence of "show−how" than transfer of "know−how." Technical cooperation was viewed by Japan as a means of penetrating the economy of Taiwan (China). Such agreements were often used as a means to "tie up" local firms by requiring them to buy parts, components, or raw materials from the technology supplier or some other equity−related firm from Japan operating in the domestic economy.

In the case of U.S. firms, there has been general agreement on Taiwan (China) that U.S. companies have provided much more actual technology transfer—whether through the process of direct foreign investment or through cooperation agreements on formal technology. Yet, even though as of 1989 the overall dollar value of approved U.S. investment ($2.75 billion) was approximately equal to that of Japan ($2.85 billion), Japanese companies have had more than twice as many cases of foreign investment (1,640 versus 750). Of the total approved foreign investment in Taiwan (China) ($10.95 billion), approximately 25 percent has been in the electronics sector ($2.75 billion).18

Relatedly, as of early 1988, the number of technical cooperation agreements involving Japanese firms (1,733) exceeded the number of U.S. cases (586) by a factor of three.19 This ratio holds even in such cases as electronics, where one study found that Japanese firms accounted for about 60 percent of the technical cooperation agreements. In essence, in spite of the differences in dollar exposure, the electronics industry in Taiwan (China) — especially the consumer electronics and component segments—has been much more linked with Japan's economy, not only in trade relations, but also apparently in terms of acquisition of technology—though most of the technology in question would fall into the general category of highly mature, standardized manufacturing expertise. The main exception is in the field of semiconductors and integrated circuits, where, for the most part, Japanese companies have not been heavily involved.

One of the theoretically interesting aspects of the technology transfer issue on Taiwan (China) has been the degree of involvement of state−owned and privately−owned firms and the extent to which foreign subsidiaries have been the focal point of technology transfer from their parent firms. The situation in the electronics industry provides a good case study, and contrasts sharply with the situation, for example, in petrochemicals. Electronics has become the island's fastest growing and most technologically advanced industry. Between 1971 and 1988, electronics output grew at a rate of over 25 percent; its percentage share of overall manufacturing climbed from about 9 percent in the mid−1970s to approximately over 12 percent by the late 1980s.20 Out of the top 500 firms in Taiwan (China), close to one quarter are involved in computers and electronics. (Approximately the same percentages are involved in textiles and garments.) In terms of capital ownership, as of 1988, close to 70 percent of the capital invested in electronics was of local origin, leaving foreign investments to account for less than 30 percent of total capital investment.

Significantly, however, the situation with respect to output and sales of electronics products is somewhat different. In spite of the fact that less than one third of the capital is foreign, overseas firms produced an average of 72 percent of total electronics output between 1974 and 1980. In fact, the share of total electronics output accounted for by foreign firms has been growing at a slightly faster pace than overall output. Moreover, during this same period, the percentage share of exports by foreign companies has ranged between 75 percent and 89 percent of overall electronics exports. (Exports as a percentage of total sales for foreign electronics firms in Taiwan (China) have averaged

about 65 percent over the same six−year period.) In the early 1980s, the former U.S.−owned RCA Tai−wan, Ltd., a 100 percent foreign−owned operation, was the top exporter in Taiwan (China), exceeding all other firms on the island. The strong foreign presence, supported by a large and steadily growing home−based R&D effort, has been one of the main contributors to the fact that electronics as a share of total exports has grown from 12.9 percent in 1971 to 18.4 percent in 1981, 21.60 percent in 1984, and 27.32 percent in 1989.

Until the 1980s, formal technology transfers in terms of patents and licenses to support domestic electronics development were not an integral part of the practices of foreign firms when they entered the electronics industry in Taiwan (China). Of course, some licenses were issued, but mainly in relation to specific consumer or industrial products; critical (high value−added) process technologies remained tightly controlled by the foreign firms. This is not surprising since, after all, in electronics the main objective of TNCs had been to use Taiwan (China) as a base for assembly. A majority of the technology transfers took place on an intrafirm basis between parent and subsidiary. As far as the domestic economy was concerned, the main vehicle for diffusion of foreign technology came in the work experience of Chinese who were either sent abroad for training or who had accumulated several years of experience in firms such as GIT, RCA, and Texas Instruments. The educated labor force of Taiwan (China), particularly engineers, provided an excellent pool from which to draw; it also gave impetus to those who saw opportunities to set out on their own. This movement made many foreign firms leery about exposing critical technical information to local hires, especially in view of the reputation of Taiwan (China) as the "counterfeiting capital" of Asia.

The strategy of the government has been to take advantage of electronics having become the most dynamic industry on the island. There has been strong support for the "localization" of firms from which the foreign parent has totally divested. Two cases where formerly foreign−owned, technologically dynamic firms operate under local management are Admiral Taiwan, a manufacturer of televisions formerly owned by Rockwell, and Chung Hwa Picture Tubes, which was formerly a joint venture between RCA and Tatung. While electronics continues to attract the greatest number of foreign firms, government policy has been to be more selective in approving investments and cooperation agreements. This is particularly true with respect to the island's three export processing zones, which are no longer seeking simple labor−intensive, assembly−oriented investments. In this regard, it is no accident that advanced electronics actually forms the core industry of the dynamic Hsinchu Science and Industry Park outside of Taipei.

As noted, however, electronics has also been the industry in which local firms have had the greatest difficulty gaining direct access to advanced foreign technology, basically because intrafirm movements of technology appear to account for most of the transfer activity. Since the late 1970s, however, things have begun to change. What is now occurring in both foreign−invested and local firms is a steady shift away from relatively simple products, such as calculators, transistor radios, and black−and−white televisions, toward sophisticated product lines, such as color televisions, computer peripherals, microelectronics, and video tape recorders. For example, the output of black−and−white televisions has diminished from a high of 5.5 million in 1980 to about 1.5 million by the end of 1988. Color television production increased from 0.54 million in 1976 to 3.9 million in 1987—though after that year total television production declined as firms in Taiwan (China) started to move production offshore. For example, color television production in 1991 reached 2.4 million sets.21 Similarly, products such as electronic calculators have also reached a plateau; in 1972, total calculator output was only 35,600 pieces, but by 1988 output had reached 68.7 million units.22 In 1989, however, there was very little growth as competitive pressures from other countries began to make themselves felt.

On the other hand, production of telephones, informatics products, and integrated circuits have been on the rise. Between 1980 and 1989, for example, telephone output grew some 33.9 percent. With the purpose of disseminating the know−how to local firms either on a royalty basis or some other licensing scheme, government organizations, such as ITRI and the Institute for Information Industry (III) are becoming the focal points for acquiring advanced foreign technology. With government encouragement, the large number of small firms that once dominated the electronics industry is giving way to more medium−size and large firms, thus making investment in R&D more plausible, as well as capitalizing on economies of scale to ensure greater production efficiency. As the demands of the domestic market grow to match those of foreign markets, for example, in terms of quality and service, the island's industrial structure will in all likelihood experience a significant change.

Several firms have already taken great advantage of the opportunities afforded by the growing domestic and international markets for industrial and consumer electronics. Acer (formerly known as Multitech) has already become a leading manufacturer of computer−related products and peripherals, a growing percentage of which is appearing in export markets. By the mid−1990s, Acer hopes to have a 4−5 percent share of the world PC market. Companies such as Acer are joined by a number of other firms such as Mitac and United Microelectronics, all of whom represent the cutting edge of the island's high−technology entrepreneurs. In consumer electronics, such firms as Tatung and Sampo have even evolved to the point of spawning their own overseas investments in the United States and several other countries. What has made these firms so successful is a combination of entrepreneurship, good management, and technical advance. The availability of foreign technology to such firms as Tatung dearly made a difference in the ability of that firm to become one of the leading corporations on the island. But, as movement into product lines that involve a higher degree of R&D intensity occurs, the requisites for remaining competitive are likely to increase further. While firms like Tatung are not yet fully competitive with their U.S. and Japanese counterparts, they are increasingly penetrating particular segments with related product lines. Moreover, they are shifting from being primarily OEM manufacturers to selling and marketing their products using their own brand names.

Foreign firms have also responded to the efforts of Taiwan (China) to move into higher−technology industries. IBM, GTE, and Matsushita have all set up R&D facilities on the island. According to Williams, this is a critical indicator of the importance that foreign firms attach to Taiwan (China). Motorola has set up an advanced, state−of−the−art semiconductor manufacturing facility—another important indicator of foreign interest in the capabilities of Taiwan (China), especially since Motorola had closed down its earlier consumer electronics facilities on the island several years ago. All the examples signify the emergence of Taiwan (China) as a strategic player in the higher value−added stages of the international division of labor.

The situation within the electronics industry of Taiwan (China) has also been replicated by the other Asian NIEs. The experience of a firm such as Tatung is not unique when compared with its counterparts, such as Gold Star in Korea. Though the consumer electronics industry in Singapore has been mainly an export "front" for several leading Japanese firms, such is not the case in Korea. Gold Star, through a combination of foreign technology, efficient production, and improved marketing, has been able to become an increasingly important actor in the consumer electronics business both at home and abroad. It is now in the process of evolving further through movement into new product areas, such as video tape recorders and, perhaps, personal computers. Of course, as on Taiwan (China), government incentives and encouragement have played a major role in Korea. Although in the final analysis, support from the government was far more extensive in certain instances than in Taiwan (China), it was a necessary, but insufficient condition for maintaining an overall competitive position.23

Korea's industrial structure, which is dominated by 10 major *chaebols* , or conglomerates, has played an important role in helping to promote a strong domestic electronics industry. Each *chaebol* has had to make its own assessments of the market and evaluate its own capabilities for responding to the opportunities engineered by the government. The experience of the Asian NIEs indicates that indigenous entrepreneurs can be relied upon to identify emerging market opportunities, to exercise good judgment in the choice of foreign technology, and to manage a variety of complex industrial tasks efficiently.24 Yet, as both the NIE governments and firms recognize, the advantages and strategies of these economies for developing consumer electronics are not the same as those that determine overall competitiveness in advanced microelectronics and informatics.

A good example of a Korean firm that has exhibited the managerial flexibility and capacity for making these types of adjustments has been Hyundai, which has been a leader in Korean construction, automobile, and heavy industries. In the mid−1980s, Hyundai decided to enter into the microelectronics industry, but in contrast to the three Korean mainstays in that industry—Gold Star, Samsung, and Daewoo—Hyundai's Chairman, Chung Ju Yung decided to forego consumer goods and concentrate on industrial electronics. Accordingly, Hyundai quickly went after IBM and became that company's principal agent in the Korean market. That base was a logical starting point for Hyundai's proposal to assemble personal computers. Unfortunately, the talks snagged, not surprisingly, because Hyundai apparently demanded too much in terms of technology transfer.

Hyundai's efforts to develop a strong, sustained link with a major foreign technological leader, such as IBM, reflects several changes in the technology strategy of Korea in general. In the past, foreign investment and extensive ties with foreign firms had been eschewed in favor of reliance on domes−

tic capabilities. In many respects, this was the strategy followed in developing the automobile industry, where in contrast to countries such as Mexico, Korea decided to establish an automobile industry not directly tied into the major multinational companies—even though each of the five major automobile producers has a link with a major foreign TNC. The Korean strategy also contrasts with that of Taiwan (China), where the approach was different, even though the longer−term objectives were the same. Koreans have basically sheltered their electronics industry from international competition and have had the local market and export markets as their primary sales targets.

Yet, while the Korean approach was possible in developing relatively basic consumer electronics products, the government has realized that move−merit into advanced stages of the microelectronics and other so−called research−intensive fields cannot be accomplished in the same fashion. Accordingly, in September 1980, July 1984, and October 1985, several major revisions were made in the policies toward foreign investment, all aimed at opening up additional subsectors and offering greater incentives to foreign firms involved in high−technology industries. Of particular interest has been the electronics technology for manufacturing 64K random access memory (RAM) and 256K RAM electronic chips, which Korean authorities have used to help domestic firms move into the 1−megabyte (MB) and 4−MB levels during the last several years.

As in the case of Taiwan (China), Korea, Singapore, and Hong Kong have all been drawn into the international division of labor in the electronics industry through their need for foreign technology, as well as through their strong export orientation. Most important, however, this process of integration has occurred at a time when each has already gone a long way forward in strengthening its indigenous manufacturing and R&D capabilities. The details of the process by which this was accomplished are discussed below. Suffice to say at this point that the relationships that now are emerging appear based on a high degree of mutual interdependence rather than dependence in the sense of drastically unequal exchange. Companies in the NIEs, with the support from their respective governments, have become attractive partners for transnationals anxious to take advantage of local technical skills, the presence of other foreign firms, and in some cases, domestic market opportunities. These enhanced capabilities have led some Japanese firms, for example, to become increasingly reluctant about providing advanced technology to some companies in the Asian NIEs (they are concerned about the "boomerang effect"), a development which reflects the extent to which these economies have been successful in using foreign technology in the past and their potential role as competitors in the future. Nonetheless, even this may be changing as government and industry leaders in Japan as well as in the NIEs have begun to realize that there may be great benefits from developing more equal collaborative arrangements.

Investment in Domestic R&D: The Role of the State in the NIE

Spurred by the imperative of "catching up" with the level of electronics development in the developed nations, each of the four Asian NIEs has substantially increased both capital investment and indirect support for building up a domestic infrastructure to support an advanced electronics industry. The focus of this investment has covered a range of items, including the formation of several government−sponsored laboratories, establishment of various industry−oriented assistance organizations, expansion of graduate−level technical education programs, and creation of special funds for supporting the acquisition of foreign technology and domestic R&D programs. While government involvement has not ensured the success of the overall effort or any specific project, it has had a significant influence and shaping effect on the process of technical upgrading through the above actions. In many ways, the state in the Asian NIEs has replicated, to some extent, the role played by government in the process of innovation in West−em Europe and Japan. Its most significant role in the electronics sector has been as an "initiating mechanism." Through its industrial targeting policies, its ability to reduce costs, and its willingness to increase rewards, the state has been able to stimulate market response and affect the R&D process itself.

The Strategy of Taiwan (China) for Technological Upgrading in Electronics: A Comparative Perspective

The attempt of Taiwan (China) to create a capable and responsive electronics infrastructure reflects many of the important features of the overall effort in the Asian NIEs to strengthen and increase indigenous science and technology (S&T) resources. The explicit efforts of Taiwan (China) began to take shape in the early 1970s, mainly as a result of a combination of rising wages, the growing cost of imported petroleum, expanding protectionism, and foreign investment considerations. In the case

of Taiwan (China), however, the greater "arm's−length" relationship between business and government—a consequence of the island's heretofore unique domestic political circumstances—has meant that the task of forging stronger links between the two sets of actors has been much more problematic than in Korea or Singapore. More specifically, historically, relations between business and government have been estranged because of the Mainlander−Taiwanese ethnic divisions that still form an important overlay for the island's economic and political affairs. With some exceptions, the private sector has not been as responsive to government's invitation to join forces. As a result, the government frequently has felt the need to play a larger direct role than in the Korean case, where financial policies have been much more widely employed. This larger role has not necessarily been reflected in overall government spending, but rather has been manifested in the "initiating" role noted earlier.

In 1978, total expenditures in Taiwan (China) on national research and development constituted 0.48 percent of GNP, or about $111 million. Government accounted for over 56 percent of the total, while the private sector contributed about 30−35 percent. More important, however, private sector spending on R&D was only 0.12 percent of sales (compared with between 2.0 percent and 3.0 percent in the United States and Japan), reflecting the generally small size of firms in Taiwan (China) and their tendency to ignore the potential value of a long−term commitment to research. By 1984 total national expenditures had climbed to 1.0 percent of GNP or $540 million; government figures for 1987 indicated that it had reached 1.16 percent of GNP level, which meant that between 1980 and 1987, R&D spending in Taiwan (China) grew at an average annual rate of 12.1 percent—faster than that of Japan (4.1 percent), but slower than that of Korea (14.3 percent). According to the "Ten Year Science and Technology Development Plan (1986−1995)" of Taiwan (China), R&D expenditures are projected to reach 2 percent of GNP by 1995. The government share of R&D spending has been gradually dropping as private sector expenditures have slowly increased. Here again, the government hopes that the private sector share of R&D will grow to 60 percent by the mid−1990s. Yet, while there are indications of growing involvement by the private sector in the overall expanding R&D activities of Taiwan (China), they should not obscure the more activist and critical role of the state, particularly in terms of promoting new strategic, technology−based industries, such as microelectronics.

Perhaps the most important manifestation of government policy, with respect to the electronics industry, has been the establishment of the Hsinchu Science and Industry Park in central Tai−wan (China). The development of the park was spearheaded by the National Science Council of Taiwan (China) and by K. T. Li, formerly the Minister without Portfolio for Science and Technology Applications. Minister Li is the individual most frequently cited as the principal architect of the economic growth of Taiwan (China) and the main force behind its push into high technology. In its broadest sense, the park represents the movement of Taiwan (China) into the next stage of economic development, where industries will be characterized by their skill and knowledge intensity rather than their mere labor intensity. The park, in several critical respects, has replaced the three export processing zones (EPZs) in overall importance. During the 1960s and 1970s, the EPZs were the keys to the export expansion drive of Taiwan (China). Now, the Hsinchu Science and Industry Park, characterized by its emphasis on high−technology industry, has replaced the EPZ as the engine driving the economy. This can best be seen in the fact that employee productivity among workers in the park averaged $110,000 in 1988, while the average level of employee productivity in the EPZs was $45,000. Investments in the park reflect the island's current target industries, particularly microelectronics, computers, computer peripherals, information science, materials, automation, and robotics. Important for the future, the park is also the site of some of the first foreign firm R&D efforts on the island—which now equal about 0.5 percent of the total R&D expenditures of Taiwan (China).

In its initial phase, the park was set up to attract high−technology companies from abroad. As of 1990, more than 100 firms had registered to set up plants; more than 80 companies had started operations. The goal of the park is to have about 200 companies in operation by 1996. Total output in 1988 reached $1.7 billion. Initially, most of the firms entering the park were fairly small in size, but most recently, larger domestic and foreign−in−vested enterprises have been increasingly involved. Criteria for selection into the park is based on a company's design, development, and manufacturing capabilities. According to current policies, the primary objective is to introduce companies with the plans and skills to improve products already developed in developed countries, rather than those planning to develop new products. Each year, the criteria for admission will be elevated to ensure that the park is at the forefront of technological innovation and develop−

ment. In this regard, it is interesting to note that as of early 1988, the average R&D expenditure as a proportion of total expenditures in the park was 5.94 percent compared with around 1.0 percent for those outside the park.

Another fundamental purpose of the Hsinchu Science and Industry Park is to capture the spillover from the presence of these firms of training, technology transfer, and direct cooperation with local firms. Authorities on Taiwan (China) hope that the private sector will view the presence of these high−technology firms as "opportunity−creating," thus inspiring some of them to move into those new industries that the government hopes will become the island's future source of comparative advantage. The geographic setting of Hsinchu Science and Industry Park is important because it is situated near two major universities (Tsinghua and National Chiaotung) and the largest industrial laboratory of Taiwan (China), ITRI. Where appropriate, faculty and personnel from these institutions serve as consultants to private firms located in the park. About 40 percent of the 16,500 person work force in the park are college graduates (79 Ph.D.'s, 508 master's degrees, and 2,049 bachelor's degrees). Many of these technical personnel were former employees of ITRI, which now has become a fertile training ground for upgrading skills of young technical people before they enter the private sector.

The role of ITRI resembles that of the Korean Advanced Institute of Science and Technology (KAIST), though heretofore it has been far less dynamic. Even though ITRI is not considered a government organization, it receives government financial assistance to a far greater extent that KAIST. Additionally, it is less "independent" than KAIST in the sense that contract research and revenues from royalties form a smaller percentage of revenue. ITRI's most important role is as a partner in high−priority, government−inspired projects. For example, in the late 1970s, the Electronics Research Service Organization (ERSO) under ITRI was the local recipient in a major microelectronics technology transfer project with RCA. Once the technology was received and mastered, ERSO then worked to diffuse the technology into the local market. United Microelectronics, one of the leading local firms in Hsinchu Science and Industry Park, was the prime beneficiary. In keeping with the government's role as initiator, UMC was formed as a local joint venture involving ERSO's technology and a 25 percent capital contribution from the government's Bank of Communications. UMC is only one of several locally−owned, high−technology firms that have sprung up in the park as the "hothouse" environment has begun to offer attractions to local entrepreneurs.

While ITRI is composed of several functionally distinct institutes, the most important is ERSO. ERSO has become the premier research center on the island in terms of the current and future advancements of Taiwan (China) in integrated circuitry and other complex microelectronics. It provides technical support to the over 40 VLSI producers and six wafer makers on Taiwan (China). Interestingly, though not necessarily by design, ERSO also serves as the training ground for young engineers, some of whom eventually leave the organization to start up their own high−technology firms, for example, ACCTON—a company formed by 11 engineers from ERSO specializing in computer network products.

ERSO's role is best exemplified by its central involvement in the island's ongoing VLSI development program. In cooperation with the Ministry of Education, the National Science Council, and several private enterprises, ERSO has set up an integrated circuit joint design center in Hsinchu Science and Industry Park to help accelerate the development of the semiconductor industry of Tai−wan (China). More recently, ERSO, with the support of the government, has also been the driving force behind the creation of a $206 million project to establish a VLSI company (Taiwan Semiconductor Manufacturing Corporation (TSMC)) that will manufacture foreign−designed "application specific" ICs, as well as some of the more general types of chips.[25] The project represents the largest investment ever made in the domestic electronics industry. The major foreign partner is Philips of the Netherlands (which owns 27 percent of the equity). This project is complemented by a national laboratory established at National Chiao Tung University and dedicated to the development of sub−micron integrated circuit technology.[26]

Today, Taiwan (China) continues to exhibit ambitions to play a major role in the global informatics industry. This is one of the main reasons why the government and local industry have decided to enter into the semiconductor race, that is, to ensure an even supply of microchips, especially dynamic random access memories (DRAMs), to the growing computer industry. As a recent *Business Week* article suggested, "Taiwan isn't just for cloning anymore." By early 1988, it ranked seventh in the world in product value, accounting for approximately 4 percent of total world production, behind the United States and Japan, respectively.[27] Production of microcomputer systems climbed from about 1,440 in 1981 to 2.4 million in 1991; manufacture of monitors for computers grew from

39,000 in 1980 to 8.4 million in 1991. The most interesting feature of the industry, however, is its rapid pace of growth over the last decade. Informatics exports have grown from less than 10 percent of total electronics exports in the early 1980s to over one third by 1988. Moreover, over 96 percent of the total production value of informatics products are exported into the world market. Computer monitors, terminals, and microcomputers have become the major export products. As suggested, in the electronics industry Taiwan (China) has moved from being a technological imitator in this field to a technological innovator. According to data supplied by the Institute for Information Industry in Taipei, for example, foreign−invested firms account for less than 40 percent of total exports. In addition, while many firms in Taiwan (China) got their primary start as OEM producers, more and more firms are manufacturing and marketing products under their own brand names, such as MITAC and ACER. A sort of division of labor seems to be emerging between Korea and Taiwan (China) in this regard, with the latter seemingly focusing more on computer products and the former concentrating more on semiconductors. For example, in 1986 Korea's exports of computers totaled $707 million, while exports from Taiwan (China) surpassed $2.1 billion. Yet, in semiconductors, Korea's performance ($1.3 billion) greatly surpassed that of Taiwan (China) ($707 million).

Korea

The experience of Korea also highlights the substantial role played by the state in promoting S&T and stimulating R&D activities in electronics.[28] As in the Taiwan (China) case, the primary objective of the Korean government has been to establish and maintain an R&D infrastructure to support electronics development and promote export competitiveness. Prior to the mid−1970s, R&D in Korea meant, for the most part, merely dismantling a foreign product and copying it. Even though government interest in R&D in the 1960s was increasing and there were instances of local adaptation of technology in traditional industries, there was little evidence of widespread indigenous innovation. In general, public concern with investment in R&D was low, and the infrastructure for local firms to draw upon was poor. By the mid−1970s, however, things began to change as the Korean government and industry both began to feel the growing pressures of international competition and to seek out new opportunities in the global electronics marketplace.[29]

Although in 1975, total investment in science and technology was only 0.5 percent of GNP, by 1979 Korea had spent about 0.75 percent of the country's GNP, which was equivalent to approximately $600 million. In 1984 that amount grew to over $1 billion or 1.4 percent of GNP. Even more impressive, investment in S&T equaled $1.5 billion (1.7 percent) in 1985 and almost $3.0 billion in 1990 (2.0 percent). The ratio of government−to−private expenditures on science and technology changed from approximately 2−to−1 in 1980 to 1−to−2 by the late 1980s. The largest amount of private R&D investment has gone into the electronics industry. In comparison with those of developed countries, in 1985 and 1986 Korean firms spent an average of 1.23 percent and 1.43 percent, respectively, of sales on R&D; they spent approximately 3.3 percent of sales on foreign technology, almost 80 percent of which was targeted to electronics technologies. In order to ignite further expansion of R&D, the government designated 500 new high−technology firms for "intensive government support" during the late 1980s. Projections contained in the government's "Year 2000 Report" suggest that R&D spending would climb to 3.0 percent of GNP in the early 1990s and to 5.0 percent in 2001—ambitious goals in view of the transition going on within the Korean economy at the present time.

The most visible and well−known example of the state's commitment to science and technology modernization was the establishment of the Korean Institute of Science and Technology (KIST) in the mid−1960s. In 1981, this organization merged with the Korea Advanced Institute of Science— which was primarily oriented toward advanced training—to form KAIST. In many ways, the creation of KAIST was unique in terms of the experiences of other developing countries. KAIST was organized as an independent, contract research organization administered by a board of trustees in which the government is a minority participant. Even though the Korean government does provide operating costs in terms of salary and some direct overhead, the actual costs of research are paid for by contracts secured from both the public and private sectors.

The importance of the KAIST phenomenon lies not merely in its direct contribution, but in the fact that it has served as a linchpin for the emergence of several other major research organizations. A good example involves the creation of the Korean Institute of Electronics Technology (KIET), which was based in Gumi, the site of Korea's equivalent of California's "silicon valley." KIET was formed in 1978 and placed under the jurisdiction of the Ministry of Commerce and Industry. It was conceived

as a hybrid organization, with participants from both government and industry. The funds for R&D activity were generated from the royalties paid by end users for technology licensed or purchased from KIET. KIET also provided facilities for private sector research as a means to prevent duplication and promote information−sharing. In 1985, however, part of KIET was sold off to the private sector and a portion was merged to form the Electronics and Telecommunications Research Institute. KAIST has also helped launch several other important organizations, including the Korea Technology Advance Corporation (KTAC), which is a venture capital firm designed to support small and medium−size firms interested in high−technology industry.

As Korea approaches the onset of the twenty−first century, it remains vitally concerned about building up its manufacturing and R&D capabilities so that it can secure a stable position in evolving global electronics industry. Accordingly, of the five key fields of activity that were identified as target areas for investment by both government and the private sector, microelectronics and information technologies, as well as manufacturing and process technologies, have received the lion's share of total investment. Localization or indigenization of capabilities in microelectronics technology is considered to be the country's highest priority. (The electronics industry's ratio of import reliance on parts and components dropped from 30 percent in 1984 to 25 percent in 1988.) In addition, efforts are also under way to train a cadre of scientific, technical and engineering personnel capable of handling the complex tasks associated with development of each of the respective fields.

Korea's determination to be a major player in microelectronics can best be appreciated by examining the development of its semiconductor industry. Korea's drive into semiconductors was pioneered in the 1970s by Goldstar's two key subsidiaries: Goldstar Company and Goldstar Semiconductor, a joint venture with AT&T that also manufactures electronics switching systems. As of 1989, Korea ranked third in the world in the production of semiconductors, though it only accounts for about 7 percent of total world production. Firms such as Samsung Electronics, which now is able to produce 1−MB and 4−MB DRAMs and which has designed its own 16−MB DRAM chip, have joined the ranks of leading global players. The intensity of the Korean commitment to microelectronics can be seen in the evolution of the industry from the 1960s when the focus was mainly on manufacturing, assembly, and packaging of discrete devices by foreign firms, through the 1970s when integrated circuit manufacturing and packaging were the predominant activities, and into the late 1980s and early 1990s when the country entered into VLSI design and production. Total production in electronics reached $23.5 billion in 1988, with $15.2 billion in exports. The key turning point in the industry occurred in 1983 when the government introduced the Semiconductor Industry Fostering Plan, a plan designed to provide start−up monies to launch a major technological upgrading in design and production capabilities. Samsung, Hyundai, Goldstar, and Daewoo have poured substantial amounts of investment capital into this area in an effort to establish the country's position as a major player in the global microelectronics industry. Between 1980 and 1985, over $1.2 billion had been invested by the four companies. By the end of 1988, Goldstar is reported to have sunk a total of $2.3 billion in total development costs for a 1−MB DRAM production facility; Daewoo Telecomm will have invested $3.0 billion in equipment and R&D facilities for manufacture of 4−inch, 1.2−micron applications−specific integrated circuits (ASICs).

In 1986, as a result of the decision of the Ministry of Science and Technology to designate 4−MB DRAM technology to be a "special research project," a semiconductor joint research institute was established that comprised government and private sector research; the new institute was an integral part of a $240 million program targeted at VLSI chip development, including the development of 4−MB and 16−MB chip technology. In contrast to initial efforts to launch an advanced semiconductor capability, which relied extensively on foreign currency loans, however, this time the Korean government agreed to provide local firms with easier access to loans from the National Investment Fund and venture capital sources. Thirteen private sector firms joined in the effort, including Gold Star Semiconductor, Samsung Semiconductor and Telecommunications, Hyundai Electronics, Daewoo Telecommunications, and Anam Industrial Corporation. Instead of providing chips primarily for the computer market, Korea's apparent goal has been to become a major source of advanced semiconductors for the growing number of sophisticated consumer electronics products, including video cassette recorders (VCRs), high−definition television (HDTV), and smart facsimile machines.

Perhaps, the best evidence attesting to Korean progress in microelectronics was the decision of Hitachi to enter into a joint venture with Goldstar Electronics in June 1989 for the production of I−MB DRAM chips. The agreement involves the first ma−

jor involvement of a Japanese firm in Korea's high−technology drive. As of 1988, Goldstar, which is Korea's third largest *chaebol,* accounted for 11 percent of overall sales (905 billion won) among the four key domestic players in the semiconductor industry: Samsung (72 percent), Hyundai (16 percent), and Daewoo (1 percent). The basis of the partnership revolved around Hitachi's need for additional production facilities for 1−MB DRAM chips and Goldstar's desire for access to advanced DRAM technology. Goldstar officials were pleased, therefore, when Hitachi decided to provide the firm with assistance for manufacture of 4−MB DRAM chips. Currently, Samsung holds a significant lead in the Korean microelectronics race by virtue of its ability to mass produce 4−MB DRAM chips—a capability that was acquired through a joint development program linked to the government−funded Electronics and Telecommunications Research Institute. Samsung's lead has also made it the beneficiary of about $3.0 million in "government incentives."

Of course, the Korean microelectronics development effort has encountered its share of problems along the way, the most serious of which continues to be swings in the pendulum between supply and demand for semiconductor components, especially memory chips.30 Most of the Korean firms lack both the technological and capital resources to compete with their Japanese counterparts in a "chip war." In addition, Korean investment in microelectronics has been largely debt based. There also have been problems with gaining access to advanced technologies, particularly as competition has become more intense and the stakes have become higher, especially in the context of the emerging Japanese−Korean battle in memory chips. Although domestic firms have developed more than 20 major technology transfer agreements over the last three years, Korean firms, in some cases, have had to approach so−called noncompetitive firms in order to gain access to desired technologies. Reservations about transferring technology to Korea have also appeared because of concerns about intellectual property protection.

Last, many questions remain about whether Korea really has the infrastructure in place to succeed within its plan to become a major player in the global microelectronics industry.31 There are shortages of qualified personnel, as well as limited numbers of people with extensive experience in managing precision−oriented industries, such as advanced semiconductors. Though the number of corporate−based research institutes, for example, has climbed rapidly, from only 46 in 1979 to 455 in 1987, the quality of many of these institutes remains in question. Moreover, although there are approximately 17,000 technical personnel in these institutes, only about 2 percent hold a Ph.D. and 24 percent hold a master's degree. These problems acknowledged, the fact remains that Korea, in terms of both the public and private sector, remains firmly committed to achieving excellence in microelectronics. If there is any doubt about Korea's commitment, one has only to look at the government's decision in March 1988 to create an HDTV Joint Development Promotion Committee; the committee has a budget of $215 million to help support the initial development and application costs of this technology.

Singapore and Hong Kong

The dynamic changes taking place in Korea and Taiwan (China) should not obscure some of the important efforts in the electronics industry that have been under way in Singapore and Hong Kong. Although much smaller by comparison, both these city−states have exhibited pockets of excellence in terms of their industrial technological capabilities.32 Singapore has been undergoing its own "second industrial revolution." The essence of this drive has been to upgrade the skills of industrial workers and in the process induce greater productivity. Because of an assortment of competitive pressures, Singapore needs to move into higher value−added industries to maintain its competitive position in the years ahead. In the late 1970s, the Singapore Economic Development Board (EDB) identified 11 key industries to target. The top priorities included precision instruments and tools, computers and peripheral equipment, microelectronics, and advanced machine tools. The effort to stimulate high−technology development has seemingly paid off in Singapore's case, especially in terms of the transformation of the electronics industry. In the late 1960s, the electronics industry began principally to perform an assembly function in consumer electronics products. As of early 1990, electronics production accounted for about 40 percent of Singapore's gross domestic product. Moreover, Singapore accounted for about 50 percent of global disk drive production and next to Japan, has become one of the world's leaders in the number of manufacturers using surface mount technology—which some have called the "technology of choice" in the production of printed circuit boards.

According to Heyzer, the state in Singapore has been an activist one, spearheading the effort to integrate the country with the international market.33 In spite of the basic commitment of Singapore's present leadership to free enterprise, state inter−

vention has been a common feature of development policy, particularly through the activities of the EDB. The EDB was primarily responsible, for example, for helping the private sector make the transition from import substitution to export promotion in the late 1960s. It was the EDB efforts that were responsible for the new statutes for encouraging foreign investment, which gave a critical boost to the drive to promote exports. Until the 1970s, Singapore was the petroleum refining center of Asia; approximately 40 percent of the total value of manufacturing came from refining−related activities. As the world petroleum situation changed during 1973−79, it became clear that the country was much too vulnerable to the vagaries of the marketplace for oil. Accordingly, from a long−term economic perspective, movement into so−called high−technology industries, such as electronics and informatics, became a fundamental necessity.

In 1979, a national R&D policy was spelled out, which highlighted a range of new investment incentives, expansion of training and education, and various increases in wages. Three key components of the program were (a) the Product Development Assistance Scheme, which allowed firms to deduct R&D expenses for introducing new products; (b) the Joint Industrial Training Scheme, which provided financial assistance for advanced training programs; and (c) the Capital Assistance Scheme, which provided concessionary financing to firms bringing new skills or technology into Singapore. In addition, the government also created a new Singapore Science Park as an adjunct to the already successful Jurong Industrial District. As in Taiwan (China), the park was designed to attract foreign firms and their high technology. In 1991, a new national S&T plan was launched as was a new information technology development scheme by the National Computer Board—both of which aimed at further fostering the movement into more sophisticated production areas.

More than Taiwan (China) or Korea, however, Singapore's efforts to build up an advanced electronics industry have been directed toward creating stronger links with foreign multinationals.34 Most of the world's major electronics firms have a manufacturing facility in Singapore—Matsushita of Japan now has seven such facilities and established what it calls a "basic research" facility in early 1990.35 Fransman, for example, in a study of

Singapore's capital goods sector, noted that the country's strategy is based on the belief that "the benefits to be derived from imported technology will be greater the more sophisticated the local capabilities."36 Along with the EDB, the other major player in this effort has been the National Science and Technology Board (NSTB), which was formed as the Science Council in 1967. Anxious to minimize Singapore's dependence on investments in mature industries, the NSTB has actively sought to strengthen indigenous manufacturing and design capabilities, so local electronics firms could establish their own market niche as well as assume an improved position in the value−added chain of U.S. and Japanese transnational companies. Yet, while it is true that the level of the technology of the manufactured products being made in Singapore has increased−−for example, all Philips audio equipment produced in Singapore is designed and developed by local engineers—the reality is that Singapore has been unable to move ahead as far and as fast as either Korea and Taiwan (China)—one reason being that its local firms have yet to attain the technological levels and degree of self−sufficiency of these other two economies.37 Moreover, its lack of indigenous technology capability has made it more vulnerable to the cyclical downturns in the global electronics industry, especially in the areas such as disk drives and semiconductors.38

Unlike the three cases discussed previously, the situation in Hong Kong has remained somewhat more *laissez faire*, or as Hong Kong officials describe it, a general situation of "positive non−intervention."39 As Fransman indicates in a study of the Hong Kong machine tools industry, government intervention generally has not been a major factor in the colony's technological advance.40 For the most part, Hong Kong has made its mark through the promotion of inexpensive, labor−intensive, low−technology consumer goods exports. The key to its success in electronics, especially consumer products, has been its flexible subcontracting situation and industrial diversification, as well as its ability to manufacture lower−priced, relatively unsophisticated products—most of which cannot be considered high technology. In 1988, electronics exports were $7.1 billion, making that industry the second largest export earner after textiles and garments.41 Traditionally, Hong Kong businessmen have not been willing to invest large sums in research;42 nor has the colonial administration viewed it as a responsibility to provide funding and assistance to support such activities.43

This is not to deny that there has been a technological dimension to Hong Kong's rapid export drive. Fransman has convincingly shown in his examination of the machine tool industry that Hong Kong firms have adopted a production strategy for a lower−income market that is more responsive to simplicity when its comes to operation and mainte−

nance. As a result, Hong Kong producers of machine tools have not had much of an incentive or need to upgrade, particularly if price increases might be involved. Judging by the past success, the experience of Hong Kong firms in consumer electronics indicates that a modest level of technological capacity can go a long way if the appropriate markets are targeted.

Nonetheless, since the 1980s, new competitive pressures have led to a reconsideration of the *laissez faire* approach to technological modernization—though this may be short−lived, since the political future of Hong Kong will not be in U.K. hands. The Hong Kong experience indicates that without certain types of state supports, there may be distinct limits to how far the "learning−by−doing" experience can carry firms in developing countries. The Hong Kong Productivity Center, which is a government−subsidized manufacturing consultancy, has helped several local firms develop computer−aided design software for about half the cost of imported technology. Many other domestic firms have also pushed ahead, dropping out of cheap consumer electronics and moving into a higher stage of the value−added chain, for example, microprocessors and nickel cadmium technology. The Hong Kong government has also been instrumental in linking universities with the private sector.

Similarly, the Hong Kong government has used its control over real estate to provide inexpensive land for the creation of the Taipo and Yuen Long Industrial Estates—both of which are slated to be sites for high−technology investments. In late 1984, in response to increasing competitive pressures, discussions arose about the formation of a government−sponsored microelectronics technology laboratory to identify advanced technology from abroad and help factories improve product designs. The idea initially received a lukewarm response from the government because the concept of creating such an entity runs counter to the theme of free enterprise that has dominated economic activity since the 1950s. Finally, the government also succeeded in getting Motorola to establish a major semiconductor facility in the late 1980s, which served as a statement of Hong Kong's long−term intentions.

Hong Kong's position in consumer electronics must also be considered from the vantage point of its eventual reunification with China in 1997. Given the pressures on Hong Kong manufacturers because of rising wage rates, a rather extensive network of subcontracting relationships has been developed with factories in the south of the People's Republic of China (PRC). Using cheap labor from China, Hong Kong manufacturers have been able to maintain their competitive position in low−end industries. Even more important, however, is growing evidence that Hong Kong firms have been looking to PRC research institutes and design units for assistance in upgrading their technology and improving their manufacturing software. New types of alliances are being formed that capitalize on Hong Kong's strength in production and China's R&D capabilities. Some interesting opportunities are clearly emerging here, though it may be too early to see how far and how fast these relationships will develop on both sides.

Prospects and Conclusions

Some scholars have suggested that one of the most significant phenomena affecting existing patterns of trade and economic intercourse in the international electronics industry has been the "globalization of technology."44 As a result of the expanded and extended diffusion of technology throughout the globe, new, alternative centers of technological capability in electronics are springing up outside the traditional centers in the United States, Western Europe, and Japan.45 The emergence of increasingly strong, indigenous manufacturing systems in such places as Brazil, Taiwan (China), and Korea has prompted greater interest in new types of collaboration with these economies. The global integration of capital markets, along with the spread of information technologies and the development of global transportation links, have further helped to facilitate this collaboration. Within the realm of international business, some evidence suggests that the traditional joint venture with its generally hierarchical character may have become a thing of the past, as it is replaced by new forms of cooperation, such as those associated with strategic alliances.

If this is indeed what is happening in the world economy today, then there are clearly important implications for the electronics development strategies of the Asian NIEs. Asia's technological assets are going to assume an increased importance as global electronics competition is played out in the years ahead. This has already occurred to some extent. In the Korean case, it involves a strategic alliance between Samsung and Hewlett Packard for the production of a high−powered work station that promises to alter the market and competition in this product area. In Taiwan (China), it involves an agreement between Acer and Texas Instruments to manufacture sophisticated computer memory

chips. It also is reflected in the emerging plan among Taiwan (China) computer manufacturers to set up a computer−industrial zone in one of the European Community (EC) countries as a way of ensuring a piece of the market after 1992.

The role of Japan is likely to become quite significant in this context, since Japanese capital has already begun to provide the cement for a more integrated regional economy in East Asia. For example, heretofore, foreign participation in Hsinchu Science and Industry Park of Taiwan (China) was conspicuous by the absence of even one single Japanese firm operating in the park. In Korea, the transition into high−technology industries was viewed by Japanese companies as a potential threat. In both cases, changes are already in progress. As noted, Hitachi has teamed up with Goldstar for the joint manufacture of 1−MB and 4−MB DRAM chips.

As has become clear in the world that is evolving, in order to attract technology, one will already have to possess some technology. With respect to electronics, this is a great source of comfort for the Asian NIEs, which are now finding that there are indeed benefits from having moved along the learning curve after all these years. At the same time, however, there are many challenges to the future success of the NIEs in the electronics sector as they face the 1990s and the next century. First, barriers to entry are growing, with respect to many of the high−technology industries that are now the focal point of economic and technology leaders in these economies. For example, the cost of building a new state−of−the−art facility for integrated circuit fabrication and production has grown over 10−fold in the past few years. Second, the ongoing efforts at technological restructuring that are occurring in these economies is being inhibited, to some degree, by the general tightening up over access to advanced technology by many who feel threatened by the NIEs. While the forces of globalization are at work, it should not be forgotten that there are also significant forces of technological protectionism also present.

Third, major questions remain in the United States and elsewhere about the viability of a business strategy that relies too heavily on alliancebuilding in the electronics industry. Strategic partnering has its advantages, but major questions of trust, cross−cultural understanding, and politics must be confronted in working to make these alliances truly mutually beneficial. Fourth, there are major information and skills barriers in terms of the adoption and application of new technologies such as informatics. This suggests that without an adequate infrastructure or training programs, many of the NIEs are going to have similar if not worse problems in assimilating many of the newer technologies.

And finally, it is one thing to desire to get beyond OEM status and enter into both product and process design in the electronics sector on a regular basis; it is another thing to succeed at doing them well. While there clearly is a strong foundation that suggests a great potential for success, the reality is that the dynamics of global competition in all segments of the electronics industry call for a degree of responsiveness and flexibility that may or may not be present in view of the existing industrial structure in many of these economies. All these factors will weigh heavily on the Asian NIEs as they seek to establish a new position for themselves in the international electronics industry.

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37. The establishment of Charter Semiconductor reflects an attempt to ensure that investments in local capabilities are not forgotten in the midst of aggressive efforts to attract foreign investment from around the world.

38. While Singapore remains the world's leading site for disk drive production, Singapore officials are anxious to diversify the country's technological base away from such a heavy emphasis on disk drive manufacturing. Interviews in Singapore, May 1992.

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41. Overall, between 40 percent and 50 percent of Hong Kong's electronics exports are derived from the operation of foreign firms in the colony.

42. About 80 percent of Hong Kong's electronics manufacturers employ fewer than 50 workers.

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13—
Development of the Brazilian Electronics Industry:
A Study of the Competitiveness of Four Subsectors

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The purpose of this chapter is to discuss the impact of the industrial policy, regime on specialization and the competitive standing of the Brazilian electronics industry. In view of the industry's diversity, the analysis will focus on four representative segments: microelectronics, banking automation, color televisions, and public digital exchanges. They span the industry's major subsectors (components, consumer and professional electronics) and, in their diversity, serve to illustrate this chapter's key proposition: that the lack of specialization has been a major constraint to the development of the electronics industry in Brazil.

The chapter argues that in the absence of specialization, producers (and research institutions) are forced to spread their resources among many competing activities. In particular, given a still narrow technical base and a broad research, development, and production agenda, an insufficient degree of specialization precludes Brazilian firms from accumulating the critical mass of technological assets necessary to improve the industry's competitive position in the most promising product areas.

That Brazilian electronics firms have been insufficiently selective in product and activity choice is a reflection of a policy regime that has moved the economy beyond the limits of efficient import−substitution, not only in electronics, but in practically all industrial activities. The Brazilian economy was, until recently, extremely closed. In 1989 the ratio of imports to gross domestic product (GDP) in Brazil was 5.7 percent, lower than Japan's (an economy nine times as large as Brazil's) and one−fifth that of the Republic of Korea's (Table 13.1). The extent of import−substitution diversification and the absence of intraindustry specialization is suggested by extremely low ratios of manufactured imports to manufactured value added (Table 13.1).

In electronics (as in many other sectors), a strategy of across−the−board import substitution has stimulated entry into new areas notwithstanding their potential to become internationally competitive. It has also led to excess entry in a number of segments. Newcomers, attracted by domestic market rents, have had to share with incumbents an aggregate demand limited to local sales. This has prevented both incumbents and entrants from reaping the substantial economies of scale that characterize most of the industry's production and development activities. In spite of the 1987 recession, few firms have exited, and production scales continue to be excessively fragmented.

A high degree of policy−induced horizontal diversification throughout the industry and the implied fragmentation of production have stimulated firms to integrate vertically.2 Domestic content requirements and other import restrictions have had a similar effect. For a number of producers, vertical integration has been the means to ensure product reliability and overall performance standards, even if it implies higher costs and dispersion of efforts.3

The lack of intraindustry specialization and the predominance of firms that are horizontally diversified and vertically integrated to an uneconomic degree help explain why the Brazilian electronics industry has been unable in most segments to approach the international price−performance frontier. There are, moreover, some indications that the competitive standing of the Brazilian electronics sector has deteriorated in the current decade.

Table 13.1
Share of Manufactured Imports in Manufactured Value Added in 1988 and Share of Merchandise Imports in GDP in 1989, Selected Countries
(percent)

Indicator	*Brazil*	*Indonesia*	*Japan*	*Korea*	*Mexico*	*Thailand*	*Turkey*
Merchandise imports/GDP	5.7	17.4	7.4	28.9	11.0	37.0	22.0
Manufactured imports/ manufactured value added	8.3	75.9	9.4	62.5	31.0	100.1	59.8

Source: World Bank, *World Development Report*, Washington, D.C., 1991; and World Bank, *World Tables*, 1991.

Table 13.2 shows changes in revealed comparative advantage (RCA) for the electronics industry over the 20−year period 1965−85.4 Two facts stand out regarding the competitive structure of the industry's major segments. First is their weak standing within the overall pattern of specialization and trade of the Brazilian economy. As of 1985, no segment had an RCA index above 0.45; the industry commanded a disproportionately low share of Brazilian exports when compared with the share held by other industries in world exports.

Second, there is a disturbing trend over the period. The systematic improvements in the RCA index for all segments between 1965 and 1980 (except for office machines, which suffered an inflection in 1975) turned into competitive losses in the current decade. Indeed, for all segments, the rates of growth in RCA were negative and significant during 1980−85, in contrast to the whole 1965−85 period. It is worth stressing that this reversal was not specific to the electronics industry, but rather characterized many of the technologically more sophisticated sectors of Brazilian industry, including electric and nonelectric machinery and transport equipment. However, what is specific to electronics is that, on average, the erosion of the industry's competitive position was by 1985 the most pronounced among all industrial segments. Only telecommunications equipment presented an RCA index—0.44—that was broadly in line with nonelectric machinery and transport equipment in 1985 (respectively 0.48 and 0.46).

The competitive losses of the electronics industry are particularly striking in view of the comparative advantage in Brazilian labor costs, the skill composition of Brazil's labor force, and a significant domestic market base. Labor costs are low for all categories of workers, technicians, and engineers. Table 13.3 reveals that, compared with four other major producers of electronics products, Brazil not only had the lowest average hourly wages (including fringe benefits) in 1985 (except for Korea), but it was the only economy where wage rates deteriorated between 1981 and 1985—they fell by nearly 25 percent in this relatively short period. Since 1985 average wages in the subsector have further deteriorated, and by early 1990 they had reached $1.10 per hour.

Even more significant than average wage levels are salary levels for engineers and technical personnel. Major electronics firms pay senior engineers (those with 10 years of experience) anywhere from one−third to one−sixth of comparable salaries in the United States (the difference is even more

Table 13.2
Brazil: Changes in Revealed Comparative Advantage, 1965−85

						Growth rates	
SITC sector no.	*1965*	*1970*	*1975*	*1980*	*1985*	*1965−85*	*1980−85*
714 Office machines	0.22	0.68	1.10	0.98	0.28	1.2	−22.2
724 Telecommunications equipment	0.01	0.11	0.44	0.46	0.44	21.0	−0.9
725 Domestic electrical equipment	0.08	0.14	0.33	0.33	0.23	5.4	−7.0
729 Electrical machinery NES	0.13	0.13	0.34	0.45	0.23	2.9	−12.6
861 Instruments, apparatus	0.02	0.02	0.11	0.23	0.14	10.2	−79.5

Source: Author's calculations based on U.N. trade statistics.

Table 13.3
Changes in Average Wages, Electrical and Electronic Industry Equipment, Selected Economies, 1981−85
(US$/hour)

Economy	*1981*	*1982*	*1983*	*1984*	*1985*
United States	10.33	11.28	11.90	12.48	12.98
Japan	5.62	5.19	5.54	5.78	6.04
Korea	1.16	1.26	1.29	1.36	1.38
Taiwan (China)	1.18	1.26	1.31	1.53	1.51
Brazil	2.07	2.42	1.71	1.44	1.49

Source: The Long−Term Credit Bank of Japan and Instituto de Planejamento Economico e Social, "Current Brazilian Economy and Business Opportunities," mimeo, June 1988, p. 151.

pronounced if the comparison is made with European and Japanese salary levels, in view of the devaluation of the U.S. dollar since 1985). Equally relevant, these firms do not find the supply of engineers and skilled personnel a major constraint in attaining a competitive market position in certain design−intensive slices of the production process. The point that should be stressed is that, potentially, Brazil has a competitive advantage not only in unskilled and semi−skilled labor−intensive areas, but also in those segments that are design and engineering intensive.

Even though the domestic market for electronics is not large relative to the scale requirements of many products, it is nonetheless significant in the sense that it provides a dynamic setting where entry is stimulated, resources are mobilized, and where learning can take place, both by doing and through producer−user interaction. Since producers of electronics goods rarely become internationally competitive soon after start−up, a dynamic domestic market becomes nearly a precondition for successful export penetration. Moreover, in many areas where economies of scale in production are less relevant, and satisfying user needs through design and engineering−intensive customization leads to one−of−a−kind products, domestic firms can find new profitable niches or substitute imports efficiently even in markets of limited size.

The Brazilian domestic market is not marginal as a breeding ground for electronics firms. In consumer electronics, its size has oscillated between 4 percent and 6 percent of the world market in the period 1977−86. In telecommunications equipment, it has varied between 1.3 percent and 2.5 percent. In semiconductors, its size has varied between 1 percent and 1.5 percent. In computers and peripherals, it has hovered around 1.5 percent. Although these shares are translated into market sizes that are sufficiently large to induce entry, their implicit scales are nonetheless too small to stimulate and sustain firm growth on an efficient and innovative basis. One finds, therefore, a number of firms in each segment, but few, and often none, with sufficient resources to move their product lines to the international price−performance frontier.

If fragmentation of production from excess entry characterizes most segments of the electronics industry, a mere reconcentration of capital around fewer, and supposedly stronger groups, will not make the industry internationally competitive. For an increasing number of products, scale requirements are such that only a sharp reduction in the number of producers would allow economies of scale to be reaped. In several cases (such as color televisions, facsimile machines, and video cassette recorders), the optimal number of firms would be one. In these circumstances, the probability of firms exercising market power would be high. Rents could be reaped without significant managerial efforts, unless new entrants and competing imports continuously forced incumbents to improve their competitive standing.

Moreover, technical efficiency may be only marginally affected by a movement toward reconcentration of capital if the degree of intrafirm diversification and intraindustry specialization remains unchanged. In fact, closing the price−performance gap (or at least ensuring that it is not further widened) now requires considerable restructuring of the electronics industry to allow an increased degree of specialization. Sectoral competitiveness is predicated upon concentrating resources in higher value added, engineering labor−intensive niches, using the considerable advantage in labor costs and of an entry−supportive domestic market to expand exports progressively.

The point of departure of this chapter is, in sum, that the electronics industry in Brazil is excessively diversified, producing "too little of too many things." In the informatics segment, for example, a number of product groups have consistently lagged in design and quality, but nonetheless they continue to be produced in relatively small volumes behind high barriers to competition. This is the case with many peripherals, such as high−speed printers, disk drives, mid−size and large memory units, mini and supermini computers, certain types of technologically more sophisticated automation and telecommunications equipment, and most of the newer generation of consumer electronics products (such as microwave ovens, camcorders, compact disk players, and liquid crystal display [LCD] color televisions). Particularly for products

that have become high−volume commodities or that have undergone radical improvements during this decade, the price−performance differential between the international and domestic markets has actually widened since the mid−1980s.5

Specialization, supported by a more open and flexible trade and industrial policy regime, should be pursued along four key dimensions:

Horizontally, across product lines. Firms would undertake to produce only what is most competitive.

Vertically, along the input−output chain. Producers would shed what can be efficiently made by domestic or foreign vendors.

Among different production stages. Firms would focus on the design and manufacturing activities that are within their level of competence and learning capabilities.

Specialization should be carried out systemically. Producers, when designing and assembling systems (providing a solution), would be able to source system components domestically or abroad.

The first section, Microelectronics, argues that the microelectronics segment in Brazil has lacked both product and production activity focus. Its development now depends, *inter alia*, on a higher degree of both horizontal and production−flow specialization. It will first be necessary to refocus the segment on a subset of application−specific integrated circuits (ASICs)—those that integrate (and miniaturize) products for which Brazil has an actual or emerging competitive advantage (certain types of telecommunication and bank automation equipment, for example). Second, the government should support producers in their efforts to achieve proficiency in design by facilitating access to tools (work stations, software, project libraries, plotters); by actively promoting in−house, laboratory, and university training of design engineers and related specialists; and by supporting "infant" users of locally−designed ASICs. Finally, integrated circuit (IC) policy should stimulate producers to break down and learn one specific set of manufacturing steps at a time (such as placement and testing) while engaging in cooperative foundry arrangements.

The second section, Banking Automation, discusses the case of banking automation and introduces the notion of systemic specialization. Systems are made up of discrete elements (such as minicomputers and input−output (I/O) devices) and a way of interlinking them to function according to certain objectives (the solution). Banking, point−of−sales and, to a lesser extent, industrial automation are segments of the informatics sector in which

Brazilian producers have an actual or potential comparative advantage. The key entry barrier to the international market is the lack of access by system houses to a broader, higher performance and more competitively priced range of products than is currently allowed by government policy. It is argued that Brazilian producers should be allowed to specialize systemically by sourcing individual components on the most economic basis while exploiting their competitive advantage in low conceptualization and design costs.

The third section, Color Televisions, examines the competitive standing of color televisions, the archetypal consumer electronics product. Its backward linkages have played a critical role in the development of the components industry in other countries. Color televisions, as an increasingly integrated product, have required IC design capabilities that have yet to be developed in Brazil. As a result, Brazilian color television producers continue to depend on the proprietary technology of foreign partners or suppliers and lack the flexibility to export because of restrictive contractual clauses. Yet, without entering the international market, producers cannot gain the scales that will generate the resources necessary to master the design of color television ASICs. However, if more emphasis had been given in Brazil to the build−up of design capabilities for custom and semi−custom ICs, television manufacturers could have undertaken the design of these ASICs jointly with specialty houses. Thus, a key technological entry barrier for Brazilian color televisions in the international market can be construed as a second−order outcome of the absence of an adequate specialization pattern in microelectronics.[6]

The fourth section, Telecommunications Equipment: The Tropicos Public Telephone Exchange System, focuses on the importance of selectivity in product development. It examines the case of digital switching equipment for small and medium−sized public telephone exchanges, the so−called Tropico project. This project has been undertaken by the *Centro de Pesquisa e Desenvolvimento* (CPqD) of TELEBRAS, the major telecommunications equipment research and development (R&D) center in Latin America. CPqD's dispersion of resources among many projects prevented the Tropico exchange family from becoming (at least so far) a cost−effective and timely alternative to imported equipment. This is not to say that there are no important external economies associated with the project, particularly in the form of product spinoffs, specialist training, and the build−up of technological capabilities. Significant economic costs have also been associated with the delays in

introducing digital technology in the Brazilian network. A longer time horizon will be needed to assess if the benefits reaped with the development of the Tropico family outweigh the costs associated with this project.

The section, Concluding Remarks, summarizes the key arguments of the chapter and draws some additional lessons from the individual case studies. In particular, it attempts to elaborate briefly on other emerging issues by examining the perspective indicated in this introductory section and the material laid out in the case studies.

Microelectronics

Market Dynamics

The world semiconductor market is expanding at a rapid rate, driven fundamentally by the growth of digital circuits (Table 13.4). The rate of growth of ASICs in particular was expected to reach over 22 percent in the period 1986−88, substantially above the average for all integrated circuits.[7] On the other hand, both discrete devices and linear circuits have been growing at moderate rates (respectively, 4.5 percent and 7.7 percent), in line with the view that demand for less sophisticated circuits will be tapering off in the next few years.

The explosive growth in demand for integrated circuits is a reflection of their extremely high rates of diffusion. The use of ICs has become generalized, with a broad range of applications in capital and consumer goods. With the number of transistorsper chip growing geometrically since 1950—40 years ago a chip could hold some 10 transistors, whereas this magnitude is now in the order of 100,000−4,000,000—their functional possibilities have been extended, and their economy−wide impact felt beyond the electronics industry.

Table 13.4
World Semiconductor Market, 1986−88

	US$ millions			*Growth* b *(%)*
Type of component	*1986*	*1987*	*1988* a	
Integrated circuits	25,702	28,235	33,091	13.5
Linear	6,353	6,640	7,379	7.7
Digital c	15,852	17,475	20,466	13.6
ASICsd	3,497	4,120	5,246	22.5
Discrete devicese	6,085	6,185	6,642	4.5
Total	31,787	34,420	39,733	11.8

a . Forecast.

b . Average per annum growth 1986−88.

c . Microprocessors, memories, standard logic devices.

d . Standard cell, gate array, programmable logic devices.

e . Diodes, transistors, tryristors, varactors, and so on.

Source: Electronics, January 1988.

Nonetheless, integrated circuits play a particularly critical role in the so−called high−technology or R&D−intensive sectors (being most important for the electronics complex itself) where projects and functional specifications of many products are reflected, in a homological sense, on the project and specifications of a set of ICs. At the extreme, as circuits become increasingly integrated (that is, as the number of devices per chip increases), they would be reflected in a single chip. The ability to introduce new products becomes, in this sense, predicated upon the ability to introduce new integrated circuits.

This has an immediate and important corollary: projecting new products for the electronics (and, to a lesser extent, other industries) will depend increasingly on acquiring, either in−house or through specialist firms, the capabilities of designing integrated circuits. The very nature of this work requires substantial interaction between user and producer. In many ways, the project is a joint venture where initial specifications are supplied by the buyer and critically evaluated, in a first instance, by the circuit designer. After a number of interactions, a common design is agreed upon.

The intensity of user−producer interaction, and the very fact that product design and circuit design will be increasingly one and the same activity, suggests that design capabilities should be fostered domestically. Achieving proficiency in IC design becomes, in this perspective, a strategic requirement for industrial competitiveness. How to foster these capabilities in industrializing countries then becomes a critical policy issue for the microelectronics segment, particularly since those countries are minor participants in world markets and have limited technological resources.

The world semiconductor market is dominated by Japan (with an estimated share of 47.6 percent in 1988), the United States (with 38.3 percent), Germany, the United Kingdom, France, and Italy. Brazil is still a marginal player, with slightly less than 1.0 percent of the market, with apparent demand outstripping domestic supply by 0.4 percent and filled in by imports (exports are small, and limited to discrete devices and linear ICs).

Within Brazil's demand structure, discrete components play a much more important role than they do worldwide (Table 13.5). Yet they are losing importance to digital ICs, the demand for which is

growing at a faster pace than either linear ICs or discrete devices. Such a trend is in line with demand dynamics in the rest of the world. Correspondingly, domestic IC production during 1986−88 expanded at nearly the same rate as digital IC demand (6.9 percent vs. 7.6 percent), whereas IC imports in 1988 were basically the same as two years earlier.

The profile of semiconductor demand in Brazil is suggestive of the stage of development of the electronics industry and particularly its semiconductor segment. The heavy concentration in discrete devices (33.7 percent of total semiconductor demand in Brazil in 1988, as opposed to 16.7 percent for world demand) not only reflects the preponderance of consumer electronics—mostly radios and televisions—relative to professional equipment (Table 13.6), but also the less demanding designs and lower performance characteristics of these and other IC−using products.

Despite efforts at expanding digital IC output, the composition of both imports and domestic semiconductor production reveals the still incipient stage of the semiconductor segment itself. At the end of 1986, there were 22 semiconductor producers in Brazil, half of which were foreign firms engaged just in mounting and testing discrete components (and linear circuits in a few cases), although one firm undertook all steps for manufacturing power diodes. Four national firms were dedicated to linear and digital ICs, of which only one (SID) dominated the diffusion cycle in bipolar technology for diodes and transistors; two others were engaged in the complete cycle for hybrid circuits; another two manufactured light−emit−ting diodes (LEDs); and one each focused on potency diodes, varistors, and solar cells.

Most locally produced digital circuits are standard logic bipolar devices (such as TTL, I2L, and ECL, whereas digital IC imports are heavily concentrated in scale−intensive and complex−to−manufacture memories and microprocessors. Some linear circuits are mounted locally with imported wafers (such as potency amplifiers), whereas most of those that are imported are circuits for car radios and color televisions. Almost all ASICs are imported; however, there are no reliable estimates of what proportion of imported ICs are application specific.

Concerning the local production of ASICs, only two firms have so far been able to dominate the project cycle (Vertice and Itaucom), although CPqD (of TELEBRAS) has designed both custom, semi−custom, and hybrid circuits (in addition to optoelectronics components). An estimated 38 ASIC projects were carried out between 1986 and mid−1988 (this number might be closer to 50, depending on how a project is defined), of which 8 have reached production stage, even though at relatively small scales; 18 are in progress; and the remainder (14) have been abandoned. There is no question that this is a poor record, particularly in view of Brazil's potential comparative advantage in ASIC design.8 Improving such a record will de−

Table 13.5
The Brazilian Semiconductor Market, 1986−90

	US$ millions				*Growth* b *(%)*
Type of component	*1986*	*1987*	*1988*	*1990* a	
Integrated circuits	223	172	230	410	1.6
Digital	113	91	131	282	7.6

Linear	110	81	99	128	−5.1
Domestic production	70	76	80	−	6.9
Imports	173	114	171	−	−0.6
Exports	20	18	21	−	2.5
Discrete devicesc	139	139	135	140	−1.5
Optoelectronic devices	8	6	6	6	−13.4
Total	370	317	371	556	0.1

− Not available.

a . Projected.

b . Average annual growth rates 1986−88.

c . Disaggregated data unavailable.

Source: GEICOM; Ministry of Communications.

Table 13.6
Brazil: Demand, 1987 and 1990

Industrial segment	*1987*	*1990* a
Consumer electronics	46	35
Informatics	23	30
Telecommunications	7	11
Automotive	19	19
Industry	5	5

a . Projected.

Source: GEICOM.

pend on having a more selective and focused structure of incentives for microelectronics, with an increased emphasis on specialization in design−intensive products and the more labor−intensive steps of the IC production cycle.

Specialization as the Focus of Semiconductor Policy

Clearly, Brazilian producers should not be encouraged to undertake the production of commodity chips (such as memories and microprocessors of wide use). The reasons are fairly straightforward: a new large−scale foundry costs anywhere from $100 to $250 million; the production process is becoming increasingly capital−intensive; minimum efficient production scales are, as a result, on a sharp rise; and the growth in scales of integration continues to accelerate, from a current upper bound of 1 million transistors per chip in the late 1980s to densities 100 times as large by the early 1990s. The use of C−MOS submicra technology (with ranges of 0.5 to 0.3 micron) is expected to then make viable memory chips of 16 to 64 megabytes, with a concomitant increase of speed from 1.0 ns to 0.05 nanoseconds (ns). In sum, entry barriers for commodity chips are high and rising, and the small window of opportunity opened at the bottom of the last price cycle has now been closed.

Many characteristics of the ASICs stand in contrast to those of commodity chips and are summarized in Table 13.7. Although the trend is for major commodity producers to migrate to the production of ASICs, making entry for industrializing newcomers more risky, ASIC production is nonetheless technologically more accessible (for most applications, a 2 micra technology is adequate), less costly (ASIC foundry costs are in the range of $40−$70 million) and, as a result, scale economies are less pronounced. Indeed, minimum efficient scales (MESs) range from 200,000 for a full custom IC to 50,000 or less for semi−custom gate array chips. Most important, however, is that ASICs are relatively more design−intensive (on a per−unit basis) than other classes of ICs, conferring potential competitive advantage to countries where engineering costs are low.

The above suggests that Brazilian IC producers should concentrate their resources in learning to design and efficiently manufacture ASICs. In particular, in view of smaller development costs and project time, lower MES requirements, and a high proportion of premounted transistors, entry barriers might be lowest for semi−custom ICs projected in gate array technology. Nonetheless, the choice of what class of ASICs to produce is predicated not only on their technological characteristics but on an existing (or rapidly emerging) market for products that require the use of ASICs. These factors naturally suggest areas in which domestic ASIC producers should be specializing. Within these criteria, the product focus might be on dedicated and semi−dedicated ASICs for certain types of bank automation devices, color televisions, telecommunications, and automotive equipment, for example.

Even if a sharp focus on certain classes of ASICs is necessary to sustain entry on a competitive basis for Brazilian semiconductor firms, it is in all prob−

Table 13.7
Major Characteristics of ASICs

		Development		
Component type	*Percentage pre−fabricated of wafer*	*Cost (US$ thousands)*	*Time (months)*	*Minimum efficient scales (output per year)*
Full custom	0	100−200	12−18	>200,000
Semicustom				
Standard cell	0	50−100	8−12	30,000−200,000
Gate array	80	25−50	4−8	<30,000

Source: GEICOM.

ability not sufficient. Some of the 1C production stages are sufficiently complex from a manufacturing standpoint, and subject to large enough economies of scale, that shedding or postponing these stages would be equally essential for attaining international competitiveness. Figure 13.1 describes the production steps for a typical IC. One set of steps is design−intensive, where costs are fundamentally determined by the price of specialized labor. Another set of steps is manufacturing−intensive, where the costs of capital and its productivity are the dominant competitive factors. These two sets can, in principle, be regarded as separable activities.9

Attaining proficiency at the design stage of IC production is within reach of Brazilian producers. On one hand, attaining such proficiency is predicated on the access of firms to computer−aided design (CAD) work stations, design software, specific project libraries, minicomputers, and plotters. Yet, such accoutrements are generally available in the international market at competitive prices, since rivalry among foundries has intensified. In fact, foundries in other countries are often eager to supply some of those tools (such as libraries) as part of their market development efforts. In the current environment, Brazilian firms could take advantage of such arrangements and avoid being locked in with particular suppliers. In the specific case of project libraries, the Brazilian government is planning to establish a freely assembled central library, in order to concentrate demand and gain scale in certain diffusion technologies.

Figure 13.1
An Integrated Circuit Production Cycle

A. Design stage

I. Objectives and functional specifications of the project

II. Project

1. Electric and logic specifications

2. Test vectors

3. Automatic extraction of netlist

III. Project validation

1. Simulation of electric/logic functions

2. Simulation of failures (test vector)

3. Extraction of electrical diagram

IV. Layout

1. Mask design

2. Symbolic edition

3. Graphic edition

4. Placement and routing

V. Layout validation

1. Check project rules

2. Extract parameters

3. Extract electric circuit

B. Foundry stage

VI. Complete project (tape)

1. Generate data base/PG−tape

2. Generate test program

VII. Mask preparation

1. Generate reticules

2. Compare with project data

3. Mask generation

VIII. Wafer fabrication

1. Physical−chemical processing

2. Wafer generation

IX. Placement and testing

1. Encapsulation

2. Electrical tests

3. Life tests

Source: GEICOM.

More fundamentally, however, competitiveness in design is dependent on the skills and cost of design engineers. According to Brazilian design houses, an adequate supply of trainable engineers is available, which would take from six months to two years to develop into a capable team of ASIC designers. Not only is the supply of skilled technicians not regarded as a binding constraint to IC design development in Brazil it is actually perceived as a competitive factor in which Brazil has a major advantage. The cost of a design engineer is in fact only a fraction (one−third to one−sixth) of an equivalent technician in developed countries. A policy of encouraging production−flow specialization in design (and the parallel development of some of the necessary tools, such as certain types of design software) might thus be the most sensible approach to ASIC development in Brazil.

The slow accretion of circuit design capabilities and the underdeveloped stage of ASIC production in Brazil is partly the result of a misguided policy focus. The first National Informatics Plan (PLANIN) not only attempted to promote too many activities in this area, but, equally important, focused on the manufacture of ICs (by no fewer than three producers) as its major policy goal in microelectronics, as opposed to, first and foremost, achieving proficiency in design. Instead, the emphasis should have been on fostering design activities by facilitating access to tools, supporting the training of design engineers and specialists, and developing a market for locally−designed ASICs. In particular, PLANIN should have backed new users attempting to improve the functional quality, and other performance characteristics of their products by incorporating ASICs.

The emphasis on ASIC design as part of a strategy of production−flow specialization should be complemented by a similar specialization policy with respect to IC manufacturing. Three firms were licensed to establish IC foundries in Brazil: SID, Itaucom, and Elebra. Of the three, SID is currently at the most advanced stage of manufacturing. After acquiring a production line for analog circuits from Philco (a Ford subsidiary), it has been able to produce linear ICs with a 2 micra level of integration within the time established by SEI (the regulatory agency that implements the Brazilian Informatics Law). However, it is only capable of encapsulating and testing digital ICs. Itaucom has basically the same capabilities as SID, whereas Elebra has exited.[10]

The manufacturing of ICs in Brazil appears to be saddled with problems of excess entry. If ASIC design activity is consistent with a fragmented firm structure, the same is clearly not true with manufacturing. In view of the large fixed and sunk costs to establish an efficient and internationally competitive foundry, the Government of Brazil should promote a cooperative arrangement among producers. Coproduction of ICs should be the policy objective. It already appears that Elebra and Itaucom will establish a yet unspecified link−up; SID might be nudged to join. Preparation of masks might be undertaken separately, possibly by a government−supported institution (such as CTI), in the demonstrated presence of strong externalities.[11]

At the same time, no attempt should be made to force individual producers to internalize certain grossly uneconomic production steps (such as generation of masks and physical−chemical processing).[12] The foundry stage has already de facto been broken down, as producers have attempted to learn and become competitive in some of the less complex steps where fixed costs are relatively small and variable costs more significant (such as encapsulation, electric, and life tests). Until a cooperative venture gets off the ground, local producers should not be prevented from contracting with foreign foundries for the preparation of masks and wafer fabrication. Such an approach to manufacturing is possibly the only way to make IC manufacturing economically viable in Brazil. Combined with an emphasis on developing ASIC design capabilities, it might ensure the competitiveness of a niche−oriented industry in Brazil in the 1990s.

Banking Automation

The Brazilian Banking Industry

The banking industry in Brazil is made up of 103 commercial banks (5 federally−owned, 24 state−owned, 56 owned by private Brazilian groups, and 18 by foreign banks) with approximately 15,000 branches spread over a large territory. In addition to traditional banking functions, the industry performs some tasks that differentiate it from the U.S. or European systems. In particular, the government relies to a great extent on banks to act as intermediaries for its taxation and transfer activities, and all utilities use it for collecting customer payments for bills. Most of these transactions involve the public use of on−premise teller services. The volume of paper that any single branch typically has to deal with is, as a result, disproportionate to the amount of demand deposits and financial papers held for its clientele. The client base of any given branch is potentially anyone who either pays taxes or bills or receives any type of transfer from the government. As noted below, these characteristics of the industry have important implications for the volume and composition of demand of data processing equipment.

The number and composition of transactions that flow through the system are indicative of its multiservice intensity. At end 1988, checks were balanced at a rate of 3 billion per year (twice as many as at the beginning of the decade, which itself was four times the number of checks balanced in 1970). In the mid−1980s, banks were annually processing 8−9 million income tax statements; 10−11 million transactions related to other types of taxes (such as taxes on industrial production, sales of goods and services, and property); 20−22 million monthly payments and other items for social security; and over 35 million yearly payments for the PIS/PASEP (*Programa de Integração Social/Programa de Assistencia ao Sevidor Publico*) and FGTS (*Fundo de Garantia de Tempo de Serviço*) assistance programs. To these figures should be added the payments and transfers of over 400 other federal agencies dealing with 30 million individuals, the more than 70 million monthly utility bills paid at individual branches, and the tax transactions related to state and municipal governments.

There is another significant reason for the growth of a multibranch banking system, in addition to its intensive use for government−related transactions. Since 1973 the rate of inflation has accelerated (with a short interregnum in 1986). It led to an increase in the velocity of transactions, as agents diversified their portfolio away from cash into bank−intermediated financial assets. It also stimulated banks to extend themselves and open more branches and offer more services in an effort to capture the inflation tax from clients who maintained positive cash balances on demand deposits.[13] The Cruzado Plan of 1986 put a break on this expansionary movement, since banks decided to rationalize their operations in view of the sudden drop of inflation. After the Plan, banks' management became more risk−averse, so that in spite of

the reacceleration of inflation, branch expansion has been taking place at a more moderate pace. New emphasis, however, is being put on portfolio control and quick response to shifting client needs.[14]

Industry−Generated Demand for Informatics Resources

The size and characteristics of the Brazilian banking system, along with the transaction environment in which it operates, have generated considerable demand for informatics resources. The introduction of data processing equipment in the 1960s coincides with the advent of financial conglomerates and the growth in concentration of financial activities.15 This movement led to the standardization of routines and activities, a precondition for the introduction of automation. It also increased banks' management control responsibilities with the incorporation of an enlarged branch base and additional services, thus making automation an operational requirement.16

At an early stage, the efforts to automate banking operations led to the introduction of centralized data processing units operating on a batch basis. As a result, data processing activities migrated away from individual branches to the centralized facilities. Typically, files were transferred manually from the branch to a regional or central office to be processed by a mainframe computer. The system's architecture, if not totally standardized, was nonetheless conventional, centered around a self−contained processing unit.

The system's topology was first modified during 1972−74 with decentralization of data entry functions. However, the most significant changes in the prevailing architecture were proposed from 1976 onward, with configurations comprising online branches and distributed data processing. Two concurrent factors promoted entry in equipment and systems for banking automation: the new informatics policy (set in mid−1976), which reserved the domestic market and reoriented demand in favor of national producers of data processing equipment, and the increasingly decentralized data handling by the banking system, relying less on mainframes and more on micro and mini computers. In 1980 domestic prototypes for on−line branches and other features of complex banking automation systems were introduced. Until 1986, when demand tapered off, banks were responsible for approximately 50 percent of the sales of computers, peripherals and related equipment of the domestic industry.

The informatics needs of the banking industry are quite diversified. They include, in addition to operational support systems (normally undertaken by centralized data processing units), those oriented to management information (based on microcomputer networks linked to minicomputers or mainframes); branch automation (to which data processing can be distributed or not); self service (for example, with the use of automatic teller machines and in−branch cash dispensers); electronic transfer of funds; credit and debit card payment; and audio response and other types of financial information and home banking.

In response to these needs, a number of systems were developed by domestic firms. The most sophisticated and functionally complete supply banking services, through a network of in− or out−branch intelligent terminals (including customer terminals), connected to a bank network or to a bank−serviced network. Data bases with client information are either centralized, stored, and processed in a host mainframe (controlling a certain number of bank branches) or distributed to each branch, and are resident in a mini or supermini, with interbranch connection made by a second small computer. The central element of this type of network is a set of programs to control data flow, being thus responsible for the interface between application software, data files, and branches.

Banking Automation and its Competitive Standing

As of 1988 there were six major and generally highly−competitive systems suppliers (Itautec, SID, Digirede, Edisa, Digilab, and Procomp) and four others of lesser importance (Table 13.8). Except for Procomp—a newcomer in the market in 1985 that was highly successful as a supplier of banking terminals—all other producers are associated with a financial group or conglomerate, which not only constitutes an important market for their products, but offers them access to group financial and other resources. In addition, several other firms are specialized in specific system components (such as modems, minicomputers, and peripherals).

According to industry sources, by mid−1988 system prices were 30 percent less expensive than internationally available products of comparable quality and performance. Users, while concurring with this assessment, note that individually, equipment prices are anywhere from two to four times higher.17 Moreover, whereas certain types of equipment are regarded as technologically equivalent to what is available in the international market (banking terminals, automated teller machines, (ATMs), cash dispensers, modems, and low−capacity printers), others are perceived as substantially outdated (microcomputers, supermicros, minis, superminis, serial printers, disk units, and

Table 13.8
Brazil: Banking Automation System Suppliers and Installed Base, 1987

	CPU/concentrator		*Banking/terminal*		*A TM*		*Cash dispenser*	
Firm	*Quantity*	*%*	*Quantity*	*%*	*Quantity*	*%*	*Quantity*	*%*
Cobra	−	−	680	0.6	0	0	0	0
Digilab	80	1.1	7,424	7.0	0	0	99	27.8
Digirede	1,804	24.3	25,864	24.4	0	0	0	0
Edisa	32	0.4	9,226	8.7	0	0	0	0
Itautec	2,820	38.0	24,300	22.9	310	36.0	100	28.1
Procomp	360	4.8	1,800	1.7	0	0	30	8.4
Racimec	0	0	795	0.7	0	0	0	0
Sid	2,325	31.3	36,058	33.9	523	60.7	127	35.7
Unsysis	0	0	0	0	29	3.4	0	0
Zanthus	6	0.1	181	0.2	0	0	0	0
Total	7,427	100.0	106,328	100.0	862	100.0	356	100.0

− Not available.

Source: Secretaria Especial de Informatica, *Parque de Equipamentos de Informatica,* August 1988, p. 43.

streamer tapes). Software quality is perceived to be good, with prices being competitive in applications (and undistinguishable in systems).

In spite of the high prices and, in many instances, of the poor performance of domestic equipment, the fact that Brazilian systems are already internationally competitive suggests that Brazilian system producers could penetrate the international market at much faster rates and become major players if they were able to source their components domestically or internationally.[18] They should thus be allowed to specialize effectively in what they do best: the design of systems and their customization to specific client needs.

This does not imply that Brazil should not be building systems components, but that in building them, it should be more selective and export−focused. The Brazilian domestic market does have a critical role: it should be sufficiently large and fast growing to amortize set−up and other entry costs. Its scale, however, should not be counted on to finance the development of successive generations of equipment. Accordingly, Brazilian producers appear to be potentially competitive to equip online and mid− to low−volume agencies, particularly those with teller terminals, data concentrators, and modems.[19] This seems to be equally the case with units for audio response (some of which have been sold recently to Portugal) and point−of−sales cash dispensers.[20] Producers might now attempt to move aggressively with those products, individually or with system parts, to the international market.

Conversely, it might be worth shedding low−volume and limited−market components, an example of which would be ATMs. By mid−1988 there were three ATM networks in Brazil: Itau's, with 253 units; Bradesco's, with 296 (including one mobile unit); and Tecnologia Bancaria (a consortium of 25 banks and 3 credit card companies), with 137.21 However, market growth potential is limited, in no small reason due to the below−cost fee banks are allowed to charge per transaction (four cruzados as of August 1988, equivalent to less than two cents). The system is estimated to grow, at most, to twice the current size. This incremental demand of 630−650 ATMs over several years will be divided between at least five firms; the implied scales appear to be far from sufficient to price these units on a competitive basis and break into the international market.

Economies of Scope in Point−of−Sales Automation

The emphasis on *systemic specialization* to take advantage of low engineering costs in Brazil—they make up 30−35 percent of the total system cost—would also be justifiable for other engineering−intensive, customer−specific areas. Examples would be point−of−sales automation (for supermarkets and other high− and mid−volume retail outlets) and, to a lesser extent, industrial automation.

In many ways, the competitive potential of point−of−sales automation is even larger than banking automation. There are at least three reasons for this advantage. First, many systems are technologically related to those developed for the banking industry, and therefore, part of their development costs have already been amortized. Second, even more than in banking, each retail business system

must be customized, since every solution is necessarily tailored to client−specific characteristics. Moreover, many of these are small solutions. As a result, engineering costs for retail and other point−of−sales automation systems—being up to 40 percent of total costs—are even more significant than in banking automation. Third, the domestic market is significant and has grown at a relatively high rate since 1984, having attracted in the period 1984−87 six new entrants (Table 13.9). The domestic market constitutes an important base for local system houses to acquire the necessary experience prior to entering the international market.

Thus, the competitive advantage of Brazilian point−of−sales systems, although introduced in the domestic market recently (1984), is already significant—their prices are approximately 30 percent lower than comparable systems available internationally. Also contributing to this price differential is the heavy weighting of point−of−sales systems in components—point−of−sales terminals, data concentrators, communication clusters, and software—that are among the most competitive equipment Brazil manufactures. It is suggestive of the competitive potential of Brazilian−designed systems that Itautec, one of the leading firms in point−of−sales automation, was able to bid successfully for installing its system in three supermarket chains in Portugal (Continente, Modelo, and Saco Cheio), competing, *inter alia,* with Nixdorf and Sweda.22

Although the same advantage in low engineering costs characterizes the area of industrial automation, one cannot infer that a competitive position as strong as point−of−sales or banking automation is achievable in the very short term. First, the technological similarities are not present; industrial automation systems are *sui generis* and somewhat unrelated to automation of banking, retail, and other services. In this sense, system firms and others have to start from scratch and fully amortize their development costs in the new product. Second, the Brazilian market is limited, not only in size, but also in the more fundamental sense that the Brazilian industry's automation culture is shallow. It has yet to form a critical mass of engineers, technicians, and other personnel who can either staff systems firms or closely interact with them. Third, there is a perception that the competitive potential of individual components (programmable logic devices for process controllers, CNC centers, CAD or compter−aided manufacturing (CAM) systems, and robots) is quite limited, although to differing degrees.

Table 13.9
Brazil: Installed Base of Point−of−Sales Terminals, 1984 and 1987

	1984		*1987*	
Firm	*Quantity*	*%*	*Quantity*	*%*
Dirirede	0	0	106	1.8
Itautec	0	0	700	12.0
Labo	0	0	140	2.4
Microservo	0	0	55	1.0
NCR	127	34.6	127	2.2
Racimec	60	16.3	1,640	28.0
Sedasa	100	27.2	1,106	18.9
Sid	0	0	115	1.9
Swedata	0	0	1,171	20.0
Zanthus	79	21.5	700	11.9
Total	367	100.0	5,860	100.0

Source: Secretaria Especial de Informatica, *op. cit.* p. 57.

Thus, even if systems integration in industrial automation often involves the provision of a customized, one−of−a−kind solution—being therefore *per force* engineering−intensive—it does not imply that just having an elastic supply of engineers and specialists is a sufficient condition for becoming competitive in the area. As suggested, a number of limiting factors prevent Brazilian firms from gaining comparative advantage, at least in the short term. Thus, even more than in the case of service−areas automation, the systemic specialization approach and a high degree of selectivity in the manufacture of system components should be pursued for industrial automation.

In sum, for all areas of automation, there should be less emphasis on manufacturing *per se* (except in cases where the potential to achieve international competitiveness is substantial and within a reasonable time frame—say, two to three years) and more on the development of system design capabilities. Fostering systemic specialization should be pursued first by redressing the asymmetry in incentives between manufacture and design; second, by promoting training in−house, at research institutions, and at universities, in critical areas of system design; and third, by promoting the export of embodied or disembodied system projects.

Color Televisions

Consumption Structure

Until the beginning of this decade, color televisions were the single most important product of the consumer electronics industry, in terms both of

growth dynamics and backward linkages with the components sector. More recently considerable enlargement of the home electronics consumption basket has occurred in developed countries, with the rapid diffusion of video cassette recorders (VCRs), laser discs, microcomputers, and other products. Progressively, color televisions are losing their status as the engine of growth of consumer electronics, as buyers diversify their expenditures towards

AVC (audio−video−computer) systems.

In Brazil, color televisions are still the major product of the consumer electronics segment. Once the color transmission system was defined in 1972 (the government opted for Telefunken's patented PAL−M, then regarded as the technically superior alternative) and Brazil's major television network started to transmit in color, color televisions were rapidly accepted by consumers. By 1980, domestic market sales amounted to over 1.2 million sets (Table 13.10). Between 1980 and 1987, the rate of growth of sales was 7.4 percent, above that of audio systems (5.0 percent) and in sharp contrast with black−and−white televisions and radios (both experienced negative growth rates during the period).

If color televisions have been the most dynamic item in the Brazilian consumer electronics industry, their exports have been marginal in terms of volume, value, and proportion of output (Table 13.11). In 1987 the industry exported slightly over 2 percent of its production, evidence of its overwhelming domestic market orientation. Exports of consumer electronics were significant for only car audio systems (radios, cassettes, and radio cassettes), and most of these were of intrafirm nature (for example, those from Philco to Ford Motor Co.) as part of a broader strategy of decentralizing production activities of these firms.

Configuration of the Industry

Nine firms currently produce color televisions in Brazil, supplying close to 100 percent of domestic requirements (Table 13.12). Although the level of output concentration is relatively high (the four−firm concentration ratio in 1988 was over 67 percent) and has been quite stable since 1980, the size distribution of output and market share dynamics, in particular, suggest that the degree of competition in the industry is significant. In fact, there is no clear market leader. Sharp's apparent leadership in 1986, for instance, was lost to Philips in 1988. Moreover, market shares have oscillated drastically for most producers—there was, for example, a rapid growth in shares (and subsequent decline) of Evadim and the progressive loss of shares by Telefunken and Sanyo. Finally, two entries took place in 1986 (CCE and Dismac), although only CCE consolidated its position due to relatively high sunk costs involved in setting up production facilities, distribution networks, and after−sales services.

The government's 1972 decision to implant in a relatively short term the PAL−M system forced the black−and−white television industry to embark in a major restructuring effort to launch a new and technologically far more complex product line. This involved establishing new technological links and setting up new (or relocated) plants in the

Table 13.10
Brazil: Main Consumer Electronics Products in Domestic Market Sales, 1980 and 1987
(thousands)

Product	*1980*	*1987*	*Growth* a
Color TVs	1,238	2,037	7.4
Black and white TVs	1,614	772	−10.0
VCRs	0	280	n.a.
Radios	5,190	4,200	−3.0
Auto radios	833	870	0.6
Audio systems	1,455	2,050	5.0

n.a. Not applicable.

a . Average annual growth rates 1980−87.

Source: GEICOM.

Table 13.11
Brazil: Consumer Electronics Exports, 1987

	Exports		*Exports/output* a (%)
Product	*Thousands*	*US$ millions*	
Color TVs	44	38.2 b	2.1
Color TV kits b	213	−	−
Black and white TV kits	7	−	−
Auto AM/FM radios	2,485	108.3	74.1
Auto radio cassettes	1,455	250.6	−
Auto casettes	3,200	−	−
Audio systems	66	4.1	3.1

− Not available.

a . Ratio of volumes.

b . Includes color TV.

Source: GEICOM.

Table 13.12
Brazil: Firm Size Distribution of the Color TV Industry, Selected Years (output levels)

	1980		*1983*		*1986*		*1988*	
Producer	*Thousands*	*%*	*Thousands*	*%*	*Thousands*	*%*	*Thousands*	*%*
CCE	0	0	0	0	2.8	1.3	85.0	4.2
Dismac	0	0	0	0	2.0	0.9	0	0
Evadim	76.2	5.2	209.8	17.3	266.0	12.0	158.0	7.7
Philco	286.8	19.5	151.8	12.5	343.0	15.5	255.0	12.5
Philips	186.8	12.7	158.2	13.1	370.0	16.7	438.0	21.4
Sanyo	135.9	9.3	100.0	8.3	130.0	5.9	75.0	3.7
Semp	174.1	11.9	105.4	8.7	233.0	10.5	202.0	9.9
Sharp	299.6	20.4	275.9	22.8	420.0	19.0	425.0	20.8

Springer National	117.3	8.0	101.2	8.4	250.0	11.3	253.0	12.4
Telefunken	190.2	13.0	105.7	8.7	174.0	7.9	150.0	7.4
Output of four largest firms		65.6		65.7		63.2		67.1

Source: GEICOM.

Manaus region (in the state of Amazonas). The concentration of the color television industry in the Manaus industrial park was determined by compelling fiscal incentives. These incentives include federal income tax and industrial value−added tax exemptions, state sales−tax credits, and access to a firm−specific quota of imported inputs at reduced or zero duty (until 1976 there was no limit on this quota—thereafter it was fixed on a yearly basis and rationed among producers). The net impact of these incentives has been translated into an estimated average unit cost advantage of 30 percent for those firms with color television assembly plants established in Manaus. No firm could thus afford to locate its plants anywhere else, and indeed, by the early 1980s, 100 percent of the industry was established in the Manaus industrial free zone.

Despite the substantial restructuring the industry underwent to produce color televisions, its domestic orientation led to plant sizes below MES. In fact, if plant−specific MESs are currently in the range of 400−600K units, 81 percent of color television output is under MES.23 Yet firm−specific MESs (particularly for R&D and marketing purposes) are in the range of 800−1.5 million. Thus, observed output levels seem to be far below what would be necessary to reap available firm−level and plant−level scale economies. Even the output of the largest producer (Sharp) would be anywhere between one−half and one−fourth of what would be minimally efficient to attain international competitiveness.

The scales practiced by domestic color television plants are explained fundamentally by the small size of the domestic market relative to a significant number of firms with sufficient technological, marketing, and financial staying power to survive intensive domestic competition. Thus, moving existing firms to international scales would require them to export a substantial proportion of their output, unless there was a major (and highly unlikely) change in the industry's configuration, with a drastic reduction in the number of producers to two or three. What, then, are the constraints on expanding color television exports?

Determinants of International Competitiveness

Many factors explain the inability of Brazilian producers to penetrate export markets. First, the process technology employed by color television producers is associated with low levels of automation. Even though color television assembly lines are generally more automated than other consumer electronics plants (with producers increasingly relying on automatic insertion and testing machines), post−assembly inspection, for example, remains a manual process.24 Generally, local producers regard themselves as being considerably behind Korean and Japanese firms. The basic reason is that small production scales do not lend themselves to high levels of automation.25

The gap between Brazilian and East Asian producers is likely to widen with the introduction of surface−mount technology (SMT).26 The use of SMT components necessarily requires programmable equipment with placement capabilities far larger than current automatic insertion machines (which range from 5,000 to 12,500 components per hour). In fact, no producer could economically invest in SMT equipment at current levels of production. If, on average, there are 400 components per color television unit, and the capability of a typical SMT printed circuit board (PCB) assembler is 4 million components per day, it would take at least 3 million color television sets to justify the acquisition of such machinery (on the assumption that ail components are produced in SMT, which is still not the case). Nonetheless, the increasing quality requirements and the changing functional characteristics of color televisions might not leave much choice for producers, who would need to incorporate SMT by either introducing SMT equipment (even if not fully using it) or importing SMT−based PCBs. However, producers would not likely be able to import SMT componentry for color televisions on a more cost−effective basis or with fewer strings attached (particularly export restrictions) than they have been able to import ICs and other semiconductor devices. To put this proposition in perspective, it is necessary to examine briefly the links between technology suppliers and local color television manufacturers.

All major color television producers (with the exception of Evadin) are either joint ventures with, or subsidiaries of, the dominant world suppliers of color television technology (Table 13.13). The asymmetric nature of these links has been reflected in what is possibly an excessive concentration of semiconductor purchases in the country of the technology supplier, relatively high IC prices, and contractual export restrictions on the use of proprietary (custom−made) ICs. Combined with lags in production technology, they have been the key obstacles to entrance into international markets.

Table 13.13
Brazil: Ownership Pattern and Origin of Technology of Color TV Producers, 1990

Producer	*Type of associations* a	*Origin of technology*
CCE	N	Samsung
Dismac	N	−
Evadin	N	Mitsubishi
Philco	N	Hitachi
Philips	F	Philips
Sanyo	JVF	Sanyo
Semp	JVN	Toshiba
Sharp	JVN	Sharp
Springer National	JVN	Matsushita
Telefunken	N	Telefunken a

− Not available.

a . Searching for new source of technology.

JVN Joint venture with national ownership

JVF Joint venture with foreign ownership

F Fully foreign

N Fully national

Source: Margarida A. C. Baptista, *A Industria Electronica de Consumo a Nivel Internacional e no Brasil,* master's thesis, Univ. de Estadual de Campinas, 1987; author's compilation.

A preliminary examination of semiconductor imports by country of origin reveals a strong (even though slightly declining) association with the nationality of the technology supplier (Table 13.14). In 1985, there were three instances in which 100 percent of semiconductor imports originated in the country where the technology supplier had its headquarters. In the majority of other cases, most (but not all) semiconductor imports fit this pattern. The only exception was Philips, explained by its more decentralized decision−making structure (in contrast with that of Japanese firms) and the ability to source U.S. purchases from North American Philips.

Not only semiconductor purchases seem to be biased toward particular countries, but there is also *prima facie* evidence that the unit prices that Brazilian firms paid for ICs are well above what has been paid by other countries (Table 13.15). Even allowing for the fact that Brazilian producers have

Table 13.14
Brazil: Semiconductor Imports by Selected Color TV Producers, 1983 and 1985

Producer	*Imported from*	*1983*	*1985 (Jan−Oct.)*
Evadin	Japan	100.0	100.0
Philco	Japan	96.0	81.3
	United States	3.4	15.3
	Germany	0.5	3.3
	Mexico	0.1	0
Philips	United States	92.9	16.8
	Holland	5.0	41.4
	Japan	1.3	26.9
	Germany		8.6
	Taiwan (China)	2.4	3.6
	Hong Kong	0.1	0
	Mexico	1.3	0
	France		2.7
	Italy	0.1	0
Sanyo	Japan	100.0	100.0
Semp	Japan	100.0	79.8
	United States		13.7
	Taiwan (China)		6.5
Sharp	Japan	100.0	100.0
Springer−National	Japan	98.8	78.7
	Singapore	1.2	21.3
Telefunken	Germany	89.6	85.8
	United States	5.2	14.2
	Japan	4.6	

Source: Margarida A. C. Baptista, *A Industria Electronica de Consumo a Nivel Internacional e no Brasil,* master's thesis, Univ. de Estadual de Campinas, 1987, Table V.6.

imported relatively small volumes of ICs (when compared with Southeast Asian countries, for example) and allowing for differences in IC specifications, there appears to be substantial overpricing by Japanese suppliers.

These distortions (excessive concentration of semiconductor purchases in the country where the technology supplier is established and where there are high IC unit prices) are particularly worrisome, since the relationships between suppliers of technology and local firms have deepened with the growing integration of color television's internal architecture. The experience of a typical Brazilian producer reflects the kind of technical change that color televisions have undergone in the last decade, first as semiconductor devices substituted for vacuum tubes, then as integrated circuits took the place of discrete components, and finally as the number of ICs proper were reduced as each undertook an increasing number of functions (Table 13.16).

Table 13.15
Japan: Volume and Unit Price of IC Exports, 1983

Importer	*Quantity (thousands)*	*Unit price (yen)*
Europe	141,389	365
Austria	4,891	238
Belgium	4,442	362
Denmark	690	522
France	5,273	476
Germany	76,003	349
Ireland	5,389	283
Italy	4,094	404
United Kingdom	29,268	413
North America	349,722	503
Canada	1,970	562
United States	334,661	510
Southeast Asia	670,634	157
Hong Kong	245,287	187
Korea	169,461	130
Singapore	101,097	137
Taiwan (China)	153,486	146
South America	13,694	589
Brazil	10,826	690

Total	1,196,221	289

Source: Japan Electronics Industry, *Japan Electronics Almanac* , Tokyo, Dempa Publishers, 1985, p. 244; reproduced from Margarida A. C. Baptista, *A Industria Electronica de Consumo a Nivel Internacional e no Brasil,* master's thesis, Univ. de Estadual de Campinas, 1987, Table V.9.

As the levels of integration grow, the importance of custom−made ICs for the functional characteristics of color televisions increases. In view of the proprietary nature of these critical custom−made ICs, the ability of local producers to penetrate export markets is diminished. Suppliers of technology are able to enforce export restrictions more effectively, as they become the exclusive source of components that determine the quality and overall product performance of color televisions.

Although Brazilian legislation forbids any kind of contractual arrangement that prevents local firms from exporting, such restrictions are de facto widespread in the industry. This is obviously difficult to document, but color television producers and officials from ABINEE (the electronics industry association) attribute the extremely low levels of exports mostly to tacit or explicit contractual restrictions. This does not imply that such arrangements are the sole factor constraining color television exports. As already suggested, low levels of automation and high component prices (not only of imports, but also of components locally produced) also explain why ex factory prices of Brazilian color televisions are an estimated 10−15 percent above international prices.27

Table 13.16
Evolution of Color TV Component Requirements, Brazilian Color TV Manufacturers, 1975−85
(index, 1975 − 100)

	Old model (last year produced)		*New models (1985)*	
Component	*1975*	*1983*	*A*	*B*
Vacuum tubes	100	n.a.	n.a.	n.a.
Transistors	100	73	54	35
ICs	100	900	500	400
Diodes	100	148	137	152
Capacitors	100	81	83	72
Resistors	100	85	70	46
Others	100	73	77	63
Total	100	84	76	60

n.a. Not applicable (product no longer produced).

Source: Margarida A. C. Baptista, *A Industria Electronica de Consumo a Nivel Internacional e no Brasil,* master's thesis, Univ. de Estadual de Campinas, 1987, Table V.5.

Such price differentials could be erased with ex−port−oriented investments that would substantially enlarge scales and increase the degree of automation. These investments are not taking place insofar as they are not part of a broader strategy of technology suppliers to diversify their export production bases and create capacity in Brazil (though export−oriented capacity is being established in more attractive sites, such as Mexico, to penetrate the U.S. market, and Portugal, to cater to the European Community (EC)). The ability of these suppliers to enforce such a strategy rests on the very unequal bargaining relationship that they have with local producers, backed ultimately by their monopolistic hold on the supply of custom−made ICs, the key set of color television components.

A Strategic Focus for National Firms

To become international players, Brazilian color television producers need to gain scales by investing in export−oriented facilities. Yet such investment is predicated on continuous access to new or improved designs and the componentry that embodies them. The basic obstacle facing local producers is the absence of local IC design houses with the capabilities to integrate an increasing number of color television functions into custom−made circuits. In Brazil such capabilities would need to be fostered by cooperative ventures between national producers and circuit design firms.

The acquisition of ASIC design capabilities in color televisions would require considerable technological efforts by design houses and managerial focus on the part of color television producers. In this sense, this effort is not consistent with extremely diversified production lines and the accompanying dispersion of development resources across products, which generally characterizes the product strategy of most color television firms. Except for Sanyo and Semp, all producers offer (or are developing) complete image and audio product lines, and many are considering ways of broadening their product range to include information systems. Thus, as demand shifts toward AVC systems, firms are responding by moving across product boundaries, even though it causes a greater fragmentation of their technological efforts (which is only partly offset by the presence of economies of scope in the development of AVC system components).

A sharper focus on developing color televisions should not preclude a marketing strategy offering consumers a broad and integrated product range. In fact, such a strategy might be a necessary condition for firms to enhance their ability to finance their development needs without resorting to debt or government subsidies. The key would be for firms to restructure their production operations so as to retain their core product (in this case color televisions) while purchasing on an original equipment manufacturer (OEM) basis all those system components that lack strong technological economies of scope with the core. Only through this process of horizontal disintegration would color television producers become internationally competitive.

Telecommunications Equipment: The Tropico Public Telephone Exchange System

Telecommunications Equipment Industry

Brazil boasts a well−developed telecommunications industry, a product, to a large extent, of TELEBRAS (the state telecommunications holding company) and government efforts to develop domestic production and technological capabilities in this key segment of the electronics sector.28 By early 1987, 117 firms supplied over 90 percent of the diversified needs of TELEBRAS, such as for telephone and telex exchanges, multiplexes, HF/VHF/UHF radios, telexes, facsimile and telephone instruments, key systems, telephone wire and transmission cables, and modems (Table 13.17). Domestic value added in the production of such equipment ranged from 60−70 percent for electronic exchanges to nearly 100 percent for telephone instruments, VHF radios, and multiplex pulse code modulation (PCM).

The value of telecommunications equipment output has grown at a high rate in the current decade (over 9 percent on an yearly basis), with demand from the public and private sectors expanding at nearly an equal pace (Table

13.18). The industry is still characterized by excess capacity in most product lines (Table 13.17), and average capacity utilization in 1987 was less than 60 percent (on the assumption that the industry's potential product was $2 billion in that year). Capacity underutilization can be explained basically by the scarcity of imported inputs and the slowdown in the extremely high rates of growth in public investment, which peaked in the late 1970s.

Excess capacity is also explained by the inability of firms to penetrate export markets on a sustained basis. In the past, Brazilian firms have been able to bid successfully in a number of instances to supply equipment to other developing countries (mostly in Latin America).29 Yet net trade is negative and

Table 13.17
Brazil: Telecommunications Equipment Industry, Production Capacity and Output in Physican Units in 1980 and 1986

				Output	
Equipment	*Number of producers*	*Installed capacity*	*Unit*	*1980*	*1986*
Public exchanges	7	1,137,950	Terminal	505,100	782,033
Private exchanges	8	273,176	Terminal	197,800	203,299
Multiplex FDM	6	66,640	End channel	26,400	32,831
Multiplex PCM	4	92,660	End channel	29,300	55,562
Multiplex telegraphy	1	13,800	End channel	4,312	21,528
Telex centers	1	10,000	Terminal	0	7,232
Radio SHF − high capacity	4	1,180	Transceiver	353	266
Radio UHF − multichannel	5	3,320	Transceiver	590	2,839
Radio VHF/UHF monochrome, duplex	2	10,500	Transceiver	2,373	8,230
Radio HF/VHF/UHF − fixed, portable, and mobile use	24	64,324	Transceiver	21,920	28,876
Monochrome, multichannel carriers	2	41,400	Circuit	22,976	7,700
Telex and fax terminals	5	18,073	Terminal	11,720	6,605
Telephone instruments	7	1,900,000	Instrument	1,388,940	1,100,691
Public telephones	2	42,000	Instrument	14,620	55,411
Key systems	7	316,220	Instrument	157,400	153,332
Telephone wire, cables	17	32,800	Ton	10,000	15,500
Voice amplifiers, line extenders	4	68,000	Instrument	43,050	10,531
Modems	11	100,000	Instrument	0	44,962

Source: GEICOM.

in the range of $60−$70 million. Moreover, the competitive ability of local producers appears to have diminished since the beginning of this decade. Export−output ratios, after increasing from 3.6 percent in 1977 to 5.0 percent in 1980, have declined to the range of 2 percent to 3 percent. Such adverse evolution is consistent with observed indicators of revealed comparative advantage for this industrial segment, which improved significantly between 1970 and 1980, and declined slightly since then (Table 13.2).

At the beginning of this decade, prices of major telecommunications products were in fact comparable (after deducting taxes and duties) with those prevailing in international markets. Yet stiff competition among international suppliers has brought down international prices significantly since the mid−1980s (electronic exchanges, for example, currently range from $120 to $180 per line, although in 1983 they were approximately $300). In a few cases (such as with microwave radios), price differences have been quite substantial all along and in favor of foreign equipment. In contrast, Brazil has maintained its competitive position in products such as multiplex PCMs and public telephone instruments (Table 13.19). Product quality is in most instances reportedly the same as that of equipment produced in developed countries. Generally, however, telecommunications equipment producers have faced difficulties in improving their competitive standing in the 1980s, in view of accelerated technical change and intense price rivalry in international markets. Domestically, the industry remains excessively fragmented, diversified, and protected from competition.

Table 13.18
Brazil: Telecommunications Equipment Industry, Value of Output, Selected Years

	US$ millions			*Growth* a *(%)*
Sector	*1980*	*1983*	*1987*	
Public sector	484.1	513.8	927.9	9.7
Private sector	136.7	100.4	240.2	8.4
Total	620.8	614.2	1,168.1	9.3

a . Average annual growth rates 1980−87.

Source: GEICOM.

The Research and Development Center (CPqD) of TELEBRAS

TELEBRAS research activities were initiated in 1973 as a set of sponsored applied research projects contracted out to universities, with a few cases of product development directed to industry.30 These projects reflected the strategic goal of TELEBRAS of ensuring that Brazil would take advantage of

Table 13.19
Brazil: Telecommunications Equipment Industry, International Price Comparisons, 1986

Equipment	*Unit*	*Average unit price*	*International unit price*
Electromechanical exchanges	Equivalent line	280	n.a.
Electronic exchanges	Equivalent line	400−−450	120−180

Multiplex PCM	Channel end	200	360
Microwave radio − analog	Transceiver	40,000	22,000
Microwave radio − digital	Transceiver	60,000	22,000
Radio UHF	Transceiver	6,000	5,000
Radio VHF	Transceiver	900	1,200
Electronic teleprinter	Terminal	4,000	3,000
Telephone instrument	Instrument	32	30
Public telephone	Instrument	450	600

n.a. Not applicable (no longer sold on the international market).

Source: Ministry of Telecommunications.

the major breakthroughs in telecommunications technology of the late 1960s and early 1970s (such as digital PCM systems replacing analog devices, time division multiplexing systems superseding frequency division multiplexers, and stored program controlled (SPC) exchanges making electromechanical equipment obsolete) and leapfrog conventional technology, in which local firms had up to then made only marginal investments.

In 1976 CPqD was formally established as the research unit of TELEBRAS; in 1980 it became an integrated R&D facility, the largest and most sophisticated applications laboratory in Latin America. In 1988 the center had a staff of 400 professionals directly engaged in R&D work, in addition to personnel from industry and universities working on a sponsored research basis, either at the center's premises (in Campinas, São Paulo) or in their own institutions, depending on the task commissioned. CPqD's 1988 budget was on the order of $60 million (including $1.2 million earned from royalties) and is allocated to a broad research agenda, consisting of approximately 80 R&D projects, most of which ultimately aim at helping establish an integrated services digital network (ISDN) in Brazil.31

CPqD has been fairly successful in transferring many of the products it has developed to industrial firms for large−scale production. By the end of 1987, 75 different products developed singly by CPqD or in association with universities (which were in charge of carrying out most applied research) and industrial firms (generally focused on the later stages of development, such as prototyping) were being manufactured by 25 producers. A special program in product technology has aimed at transferring technology developed at the center, through the provision of a wide array of elements needed to make the transfer effective (including electromechanical packing, the thermodynamics project, printed circuit boards, components qualification, materials, process norms and parameters, and necessary documentation).32

Yet the key to successful technology transfer has been the practice of shifting teams of engineers and technicians from CPqD to the premises of industrial firms. These buffer groups are the *de facto* carriers of industrial knowledge that no amount of formal documentation could replace. The relative success of CPqD with marketable products that in the case of many other research institutions would have remained on the shelf is explained by its emphasis on transferring technological capabilities though these buffer teams.33

CPqD's accomplishments have not been small, including its managers' ability to assemble a task−oriented team of professionals in−house and in sponsored institutions, with a focus on applications. CPqD's role was crucial in improving the technological capabilities of telecommunications equipment producers (thus complementing TELEBRAS's provision of a stable market for their products through consistent procurement policies). Nonetheless, CPqD's product development efforts have suffered from the excessively broad scope of its research activities. In this sense, it mirrors the lack of specialization and product focus that characterizes the production of telecommunications equipment (and, more generally, of electronics products) in Brazil.

The Center's original priority was in the field of switching. This reflected CPqD's mandate of tackling more complex technologies, involving products with higher technical and development risk and with potentially larger markets. Yet, the perception that the country faced major technological

gaps for most telecommunications equipment and the unwillingness to adopt a sequential strategy for closing these gaps led CPqD's management to adopt a much less focused research agenda.[34] A budget that varied from $30 million at the beginning of this decade to the current $60 million thus had to be allocated to an array of 80 research projects within 7 priority areas:

Electronics switching—the *Tropico family* of digital public switching exchanges.

Digital transmission, including digital multiplexers for telephone, data and text, and transmission equipment as digital radios, processors and codifiers.

Optical communications, such as optoelectronics devices, lasers, photodetectors, optical fibers, optical cables, application systems, and equipments.

Data and text communications, including development of concentrators, computer networks, supervision and control systems, testers, analyzers, and equipment for end users.

Satellite communications equipment, such as parabolic antennas, power transmitters, low noise amplifiers, and other elements for earth−to−satellite communications.

Outside plant materials, tools, and equipment, including optical cables splicing and quality testing, corrosion, electric protection, new alloys, and resins.

Components and materials, such as thick film and thin film hybrid circuits, custom−made ICs for decadic push−button telephone and other applications.

An absence of research focus and specialization has led to systematic delays in the CPqD research chronogram and, therefore, to delays in the market launching of its applications. Even when adjusted for skilled labor cost differences, a budget of $60 million is minute within the scope of CPqD's research agenda. Budgetary allocation would average less than $8 million per program or $1 million per project, whereas each program would in itself justify the whole budget. The experience of the development of the Tropico family of digital exchanges, possibly CPqD's most ambitious program, points to the costs of engaging in a major research undertaking within an institution that has scattered objectives and very limited resources.

The Tropico Program

Research on the Tropico family of digital SPC public telephone switching exchanges started in the mid−1970s.[35] The Tropico family comprises a total of five products—two in production, one with start−up planned for 1989, and two others with no firm production dates yet:

Tropico C—a subscriber line concentrator for up to 192 lines, under production since September 1983.

Tropico R—small local−tandem exchange for up to 4,000 lines, field−tested in December 1984 and transferred to industrial firms soon thereafter. It has been in production since 1986.

Tropico RA—medium−size local−tandem exchanges for up to 20,000 lines, under development and scheduled to be delivered by the end of 1989.

Tropico L—large local−tandem exchange for up to 80,000 lines. It is still in the planning stage.

Tropico T—large toll exchange for up to 50,000 trunks, also at the planning stage.

The market for public exchanges in Brazil has averaged 540,000 lines annually between 1980 and 1986 (approximately $162 million yearly at $300 per line). In 1987 it jumped to 900,000 lines. TELEBRAS's long−term objective is to expand Brazil's installed base from 7.8 million lines (at the beginning of 1988) to 25 million terminals by the year 2000, of which 67 percent would be based on digital technology. The basic policy for production and procurement of telephone exchanges was initially set in the mid−1970s. An agreement was reached with large foreign firms that assigned them a slice of the Brazilian market of public telephone exchanges if they were to undertake the local manufacture of large−scale switching equipment. Thus, switching equipment for major cities was reserved for LM Ericsson (São Paulo), NEC (Rio de Janeiro), and Siemens (Curitiba). In the rest of the country, which accounted for 30 percent of the market, there was a measure of open competition. The basic price for the reserved market was established in 1975, with price escalations agreed thereafter.

The production of digital equipment at that time (1975) was reserved for products based on Brazilian technology, on the presumption that CPqD's Tropico design would be transferred to industry by the end of the decade. However, as the research and industrialization of the Tropico system was not forthcoming according to the initial chronogram, in May 1984 the Ministry of Telecommunications relaxed its restrictions. It allowed the introduction of large (over 10,000 lines) and medium−sized (4,000−10,000 lines) public exchanges based on foreign digital technology to be produced and installed in Brazil by three firms: LM Ericsson, NEC, and Siemens (later Equitel). The three were

to have Brazilian−owned majority voting shares (51 percent of the one−third voting shares). The small exchange market continued to be reserved for wholly−owned Brazilian firms using the Tropico technology.

The current policy dates back to 1985 and is a variation of the 1984 directive. It continues to assign the small digital exchange market to Tropico R equipment and allows the market for large public exchanges to be supplied by equipment based on foreign technology. Yet it guarantees 50 percent of the mid−sized market to Tropico RA (as soon as it becomes industrially available). Tropico R exchanges started to be delivered in 1986 (some 80,000 lines), and production was significantly expanded in 1987 (to 120,000 lines). Tropico R is currently produced by Elebra and PHT, whereas SESA and SID Teleinformatica have been licensed to start production. In addition, three other groups—Multitel, ABC, and Sul America—have displayed an interest in entering the small digital exchange market.

Starting in 1989, Tropico RA (which in its first stage will have 4,000−10,000 terminals, to be extended to 16,000 terminals at a second stage, and later to 20,000 terminals) will be produced by Elebra, PHT, and SID Teleinformatica. TELEBRAS has undertaken to contract with Elebra and PHT for 60,000 lines on a yearly basis over a five−year period upon their commitment to codevelop with CPqD the RA system, picking up 25 percent of development costs. The trend, however, is for producers of Tropico R to be licensed eventually to produce the RA equipment because of the significant economies of scope involved in the production of Tropico R. By 1990, five to six producers are expected to be sharing an estimated annual demand of 200,000−250,000 lines per year for Tropico's small and medium−sized terminals.

The procurement policies of TELEBRAS (and its operating subsidiaries) and CPqD's long−term technology development efforts have allowed Brazilian firms to acquire significant production and technological capabilities in the area of digital switching technology. Whether these articulated efforts have been worthwhile is a fairly complex question to answer. Substantial costs have been associated with it, both direct resource expenditures (in product development and setting up production facilities) and indirect costs associated with the delay of introducing digital technology in the Brazilian telephone network.

Informed estimates of Tropico's total development costs range from $85 million ($55 million direct and $30 million indirect costs) to $200 million (of which $100 million would be direct costs and the other $100 million indirect), not insignificant amounts by developing country standards. To these costs should be added the continued obsolescence of a segment of the Brazilian public exchange system, which failed to be digitalized while TELEBRAS waited for the Tropico design to become operational. During five years (approximately 1980−85), TELEBRAS was directed to buy large volumes of electromechanical exchanges (crossbar and crosspoint) in spite of the availability of a clearly superior alternative in the form of foreign digital technology. Possibly the major implication of this considerable delay is that it makes more distant the goal of an integrated services digital network.

Such indirect costs of the Tropico program might have been smaller were CPqD's research program more focused on electronic switching development—as was the original intent of the institution—and if its chronogram and targets were more realistic. To put Tropico's development expenditures in perspective, suffice it to say that even if CPqD's entire budget were allocated to the Tropico program, it would have taken 3040 years to match the expenditures that major digital exchange producers incurred to bring successful systems to market. Moreover, the relatively small volume of resources ($10−$20 million per year over 10 years) allocated for Tropico's development did not allow for the exploitation of significant economies of scale in R&D activities.

Finally, unit costs for the Tropico equipment are high by international standards. By early 1988, 200,000 Tropico R (and C) lines were delivered, 250,000 more contracted and an additional 350,000 expected to be procured by 1991, totaling 800,000 lines. Development cost estimates per line range from $105 to $250, whereas domestic price is $400−$450 (including royalties of 3 percent paid to CpQD). Considering that royalties are just $12−$13 per line, the total cost of the Tropico exchange for TELEBRAS (development costs net of royalties plus price paid to manufacturer) would be in the range of $493 to $587 per line, which compares unfavorably with international digital switching prices of $120 to $180 per line (mid−1988).

These high unit costs cannot be imputed directly to the expenditures related to the acquisition digital switching technology (insofar as royalties are just over $10 per line). They cannot be separated, however, from the Tropico's program. To the extent that unit costs are driven up by the small scales practiced by Tropico's producers and a weakly competitive environment, Tropico's prices

are partly an unintended outcome of TELEBRAS attempts to attract new producers to manufacture the Brazilian design. It further crowded a market where no more than two to three producers would be justified and where all producers, except for Ericsson, are well below minimum efficient scales. Entrants' production volumes have in fact been well below 100,000 lines per year, whereas international scales are on the order of 500,000 lines per year. At the same time, TELEBRAS' policy of reserving certain market slices for individual producers and assuring them minimum demand has decreased some of the potential benefits of a more crowded and competitive market. In many ways, each producer can behave as a (regulated) monopoly, even though it is not alone in the market.

Nevertheless, a number of apparent benefits need to be taken into account when evaluating the Tropico program. The first relates to the nature of the product itself. Tropico R is argued to be a highly reliable, multifault−tolerant system, especially adapted to Brazilian environmental conditions.[36] Tropico R is also fairly simple to operate, built around three types of modules and only 25 types of printed circuit boards required to handle all its operational capabilities.

Similarly, Tropico RA holds only 50 different types of PCBs, many of them the same as for Tropico R. In contrast, Ericsson's AXE requires 65 types of boards just for the central processor, in addition to other PCBs specific to its terminal, operation, and maintenance functions. The relatively small diversity of Tropico's boards also plays an important role in simplifying production engineering requirements. Finally, Tropico's standardized, compact, and modular structure, with a completely decentralized and distributed control architecture, is supposed to reduce sharply the volume of spare parts in inventory and allow for flexible growth and ease of maintenance.

A more compelling view in favor of Tropico's development is that its R&D outlays act as entry costs that industrializing countries like Brazil have to incur if they want to enter an exclusive club (to which only three other developing countries—the People's Republic of China (PRC), India, and Korea—have had what amounts to a still incipient access). The country would be paying for the acquisition of a critical technology that is not available off the shelf. According to this argument, training highly−skilled teams of specialists and accumulating design and manufacturing capabilities ina critical area of digital technology would bring large positive externalities in the form of product and firm spinoffs, and would accelerate technological maturity.

The significant learning that has taken place as an outcome of the development of Tropico C and R, for example, has already allowed for a shorter development time for the next member of the family, the Tropico RA. This has been brought from design to manufacturing in 36 months at a fraction of the development cost of Tropico R ($20 million). Beyond that, however, the externalities associated with Tropico's development, although real, are hard to document and compare against the costs that Brazil has incurred in developing the Tropico family.

It should be stressed, nonetheless, that the industrial and technological strategy pursued for the telecommunications equipment sector needs to undergo significant adjustment if it is to improve its competitive standing. First, the sector would benefit from a more competitive environment stimulated by a policy regime that would not deter but promote competition among local producers (by phasing out market reservation and other anticompetitive arrangements). At the same time, producers should be induced to become more involved in the international market both as exporters and import competing manufacturers.

Second, as with the rest of the electronics industry, development and production activities should be far more specialized and selective, allowing more resources to be channeled toward products and technologies in which Brazil is competitive or highly likely soon to become (as for certain transmission equipment—PCMs with 30, 120, and 480 channels, telegraphic multiplexes, and public telephones) and shedding others that do not offer such prospects. In uncompetitive areas, Brazil would rely on imported equipment.

The sector would thus benefit from a more balanced mix of technology acquisition, adaptation, and local development. Only a limited amount of R&D can be efficiently carried out with $70−$80 million (estimate of total 1988 R&D expenditures in the sector, including CPqD's outlay of $60 million). Although these are the largest industry−specific R&D expenditures in Latin America (with the possible exception of the chemical−petrochemical complex in Brazil), they are a small fraction of the individual R&D outlays of large international equipment producers. In the highly dynamic environment of the electronics industry, these foreign firms are responsible for pushing out the technology frontier, usually by taking up small segments of the frontier at a time.

CPqD (and Brazilian firms) should have a similar approach to innovation and adaptation, with development activities even more niche−oriented in view of very limited resources. In engineering−intensive areas, where product customization is key to competitiveness, designs could possibly be locally developed, taking advantage of low engineering costs. For other products, designs might have to be imported and adapted to local conditions.

Concluding Remarks

This chapter has argued the importance of specialization for Brazilian electronics firms. It would allow them to concentrate their relatively limited technological, marketing, and financial resources on a smaller set of products.

Selectivity in the choice of what to produce and what production activities to undertake becomes particularly critical for technical change. Unless Brazilian producers are able to concentrate technical staff (and other resources) on a few promising areas, technological capabilities will remain limited to pursuing outdated development targets. Moreover, by specializing along their lines of competitive advantage and shedding others, firms would be expanding output within an increasingly focused product range. This would enable them to reap previously unexploited economies of scale. Thus, a larger volume of resources would become available for design and development, production planning and organization, quality control, and other activities critical to the competitive standing of producers.

The key issue is how to establish a structure of incentives to stimulate firms to improve their competitive standing domestically and internationally. The basic presumption is that what is currently constraining the electronics sector is a policy regime that led to excess diversification and fragmentation. Reforming this regime would be in many ways a precondition for development of the sector.

An improved structure of incentives would help firms make better use of Brazil's pool of inexpensive engineering labor and take advantage of the country's relatively large domestic market. The chapter stresses engineering labor cost differentials as a basis for specialization, although cost ratios are expressed without adjusting for differences in quality or levels of experience. The qualifications for a senior engineer (say, with 10 years of experience) in an advanced industrial country and in Brazil may be quite different. Generally, however, firms regarded the cost and the quality, versatility, adaptability, and trainability of Brazilian engineers to be a major competitive asset. Moreover, once technical labor had access to complementary factors (such as updated work stations and software), productivity differentials appeared to be substantially lower.

The domestic market is the other basic endowment that would guide resource allocation and specialization in the electronics industry. The Brazilian market, like that of other industrializing countries, is not large enough to be the sole or even the main outlet for products with large development costs, massive scale requirements, or high price elasticity (sensitivity), and that furthermore are generally regarded as commodities. Yet the experience of the segments reviewed in this chapter also emphasizes that even though an export−oriented strategy seems to be necessary to sustain product development over the longer term, the role of the domestic market is multifaceted and should not be understated.

First, the domestic market is a naturally protected space, functioning as a learning environment for technical labor. Much of this learning is derived from user−producer interaction, for which physical proximity is generally a critical variable. In addition, the domestic market is also a natural breeding ground for new firms. At early stages of product launch and often beyond, entrants often need to accumulate production and marketing experience before identifying niches and penetrating export markets.[37]

Second, many activities in electronics are spawned and sustained by the domestic market, for which exports are incidental. The experience of Brazil, as well as of smaller industrializing countries, points to a number of product areas, mainly in professional electronics, and office, banking, and point−of−sales automation, where domestic firms have been able to become competitive. In most cases, these are design and engineering−intensive products, with quality and performance characteristics depending to an unusual degree on user−producer interaction. Sometimes the product is a system made up of individual pieces of equipment, which are mere commodities themselves. High value is added in configuring and integrating the system so as to satisfy specific customer needs, thereby offering a unique solution to the customer problems (Banking Automation section).

Other times the product is a discrete piece of equipment (such as a printed circuit board, procured domestically or imported) modified and adapted to local conditions and needs by engineers and other technical labor. There are also examples of innovative, locally−produced, customized products (such as in−circuit testers, analyzers, special types of telecommunications equipment) for which a domestic niche market has been identified and export orders eventually secured. In sum a multiplicity of entry points exists for electronics firms in Brazil and other newly industrialized countries

without relying necessarily on the external market for growth and sustainability. In most cases, however, successful entry is predicated on the availability of minimum domestic endowments, in the form of engineering and other technical labor; a set of informed and demanding users (and, more generally, a user culture—see discussion on industrial automation at the end of the section, Banking Automation); and a strategy of avoiding dispersion of resources among an excessive number of competing activities.

The case studies indeed illustrate over a broad spectrum of industrial segments the recurrent costs of failing to specialize and the potential gains, both direct and roundabout, of greater focus of activities. They also make the point that policies focusing on the acquisition of technological capabilities should take into account the diversity of economically useful knowledge associated with developing, manufacturing, and using individual products or systems of products (Table 13.20). A broader and more balanced approach might substitute for the excessive (and sometimes exclusive) focus on product development and manufacturing (represented by cells I, II, and V).

In particular, mastering systems development and application technologies (cells III and VI), for example, should not be conditional on the acquisition of design or manufacturing capabilities for any of the system's components. The economic significance of the former often dominates the latter. This seems to be one of the main lessons drawn from the discussion of financial and retail automation (the section, Banking Automation). Yet it also appears to be equally applicable to the Brazilian experience with the Tropico design (the section, Telecommunications Equipment: The Tropicos Public Telephone Exchange System). The design, operation, and maintenance of a digitalized telephone network became (for close to five years) contingent on CPqD's success in developing an individual product family. In view of CPqD's inability to establish clear development priorities and muster the necessary resources, this ultimately proved to be a risky and costly strategy for the country to pursue.

The case studies also suggest that even though a movement toward increased specialization would bring strong economic benefits, specialization *per se* should not be regarded as the *deus ex machina* for industrial competitiveness. New organizational forms leading to interfirm cooperation, for example, might be important in enhancing the competitive position of individual segments. In only some cases would these new forms lead to increased functional specialization. Thus, in microelectronics, cooperative foundry arrangements among IC producers seem essential to the viability of the industry in Brazil (the section, Microelectronics). At the same time, temporary government support for joint mask preparation might be warranted in view of the strong externalities of having them made domestically. In color televisions, cooperative agreements and even alliances may be needed between national producers and circuit design houses if they are to break into export markets. It would be a major step to move beyond a traditionally subordinate position with respect to technology suppliers, which has led to high component prices and (tacit) contractual restrictions on external sales (the section, Color Televisions).

New corporate forms also may be required in response to demand shifts or technological opportunities. Conglomeration of consumer electronics firms may be inevitable in light of the trend toward home entertainment systems. Yet offering a broader range of products does not mean enlarging the firm's manufacturing base, but rather improving its ability to access system components on an OEM basis, for example, while concentrating its production efforts on core products. Conglomerate forms would be taking shape downstream, in areas of marketing and servicing. The presence of significant technological economies of scope, however, would be a strong argument for widening the production core (as in the case of point−of−sales au−

Table 13.20
The Technology Opportunity Matrix

Function	*Product*	*Manufacturing process*	*Systems/networks*
Development	I. Individual product	II. Plant/equipment	III. Whole systems (architecture and software)
Application	IV. Operation and maintenance	V. Production engineering, planning, and organization	VI. Network operation and maintenance

Source: Based on discussions at GEICOM.

tomation), even within a strategy of downstream conglomeration with specialization.

Finally, a movement toward specialization and increased penetration of export markets would also be predicated on well−focused training programs (such as in areas of system and component design). In view of strong externalities associated with training activities, they should be supported by the Government of Brazil and should be approached as a joint undertaking between industry and education and research institutions.

Notes

1. Research for this chapter was part of the Organization for Economic Cooperation and Development (OECD) Development Center's project on "Technological Change and the Electronics Sector—Perspectives and Policy Options for Newly Industrialising Economies." The views expressed herein are those of the author and should not be attributed to the World Bank or its affiliate organizations. The author would like to thank Mr. Salomao Wajnberg of the Interministerial Group for Components and Materials (GEICOM) for his generosity with data, time, and insights, as well as Professor Peter Evans, Dr. Dieter Ernst, and other participants of the OECD workshop on the electronics sector (June 1989) for useful comments and suggestions. He is also grateful to Ms. Stephanie Gerard for her editorial assistance.

2. This is the converse of the classical proposition that vertical disintegration accompanies an enlargement of the market and increased production scales. See J. Stigler, "The Division of Labor Is Limited by the Extent of the Market," *Journal of Political Economy*, June 1951.

3. In one example, a major producer of computer sys−terns was manufacturing its own floppy disk drives because of its poor experience with suppliers. Two engineers were reassigned from the firm's major product line to do development work in this area.

4. The index of RCA for a good (or a subsector) is defined as (Xi/X)/(Xiw/Xw), where Xi is the country's exports of good i, X is the total country's exports, Xiw is the world exports of good i, and Xw is total world exports. RCA indices are quite sensitive to the competitive position of individual subsectors in the national economy, and the changes in the index are indicative of shifts with respect to the world price−performance frontier.

5. A growing lag has been observed, for example, in color televisions. Domestic products have converged to 20−inch tube technologies, whereas internationally the trend is toward larger tube sizes and higher levels of resolution (as well as an increasing degree of integration in audio, video, and computer capabilities). On the other hand, the ratio of international to domestic prices has grown from 1.3−to−1 to 2−to−1. In computer peripherals, dot matrix printers' international−domestic price differentials were in the range of 3−to−1 at their early stage of production in Brazil (and have remained so since), whereas for laser printers, this lag has grown to 5−to−1. In telecommunications equipment, a combination of overdesign (products taking five to eight years from conception to market launch) and obsolete componentry is increasingly making products and systems obsolete before they are commercially exploited. The yet−to−be−marketed Tropico RA, for instance, is taking considerable time to be developed and is not being projected in surface−mount technology or making full use of microelectronics componentry.

6. Integrated circuit design capabilities are proving to be of increasing importance for color televisions as ICs concentrate a growing array of new functions and those traditionally undertaken by discrete componentry.

7. More recent figures show that the share of ASICs in the digital IC market grew from 23 percent in 1982 to 39 percent in 1988; it is expected to reach 58 percent in 1993. Among ASICs, the highest growth rates are projected for custom ICs (20 percent per year between 1987 and 1993, versus 16 percent per year for semicustom ICs). See Integrated Circuit Engineers (ICE), "Status 1989—A Report on the Integrated Circuit Industry," mimeo, 1989.

8. Possibly the most successful design house is Vertice, which is now associated with SID (the informatics division of Sharp, a major Brazilian electronics group). In two years it has projected 28 ICs, five of which have been exported directly (as a project) and three embodied in other products. Vertice is small flexible, and cost efficient, while its links to the group SID/Sharp provide substantial internal demand for its projects (the group purchased $26 million annually during 1988−89 in microelectronics products, a growing proportion of which are application−specific ICs). Vertice's exports are based on extremely low engineering costs and occasional excess project capacity, the latter allowing Vertice to enter new markets at marginal costs. Vertice's and occasional experience is indicative of the potential for successful ASIC design in Brazil.

9. "Although involving a high degree of technical expertise, designing ASICs may be seen as an activity external to the semiconductor industry proper. This activity requires intensive use of sophisticated CAD tools and other kinds of complex software which perform computer simulation of the functional and physical characteristics and behavior of the component under design. Since the physical characteristics depend, to a great extent, on the process by which the component will be manufactured, the technical parameters of this process must be modeled into the simulation software. However, once this software is available, design can take place as an activity entirely independent from production . . . . From an industrial standpoint, design capability does not imply, nor is it directly linked with, the capacity to manufacture the components." See David Rosenthal, "Microelectronics and Industrial Policies in Developing Countries: the Case of the Semiconductor Industry in Brazil," University College, London, July 1987 (Ph.D. thesis).

10. Itaucom has an agreement with AMI to access their libraries of gate array and standard cell IC projects. On the basis of Itaucom's project tape, AMI prepares the mask and fabricates the wafer, which is then returned to Itaucom for encapsulation and testing.

11. The advantages of having mask preparation and physical−chemical processing done domestically include the greater control that local designers would have over

the production process, and an expected reduction in manufacturing time. Foreign foundries currently take two to three months to prepare masks and six months for physical−chemical processing. Such extended periods are the norm for smaller, nonpreferential customers.

12. Producers committed to internalizing all manufacturing steps for the production of ICs have been granted certain incentives; those unable to fulfill such a commitment will have to return double what they received from the Government of Brazil.

13. In 1987 the total inflation tax was estimated to be about 7 percent of GDP, of which some 3.5 percent was absorbed by the banking system.

14. Macroeconomic instability and an inflationary environment led to increased demand for computational resources, since the number and speed requirement of transactions grew substantially. Banco Bradesco, the largest private bank in Brazil, undertook, for example, an average of 240,000 open market operations each day before the Cruzado Plan. During the Plan period, the number of operations fell to 100,000. By the end of 1989, however, as inflation continued to accelerate and as individual investors attempted to protect themselves from its effects by moving into indexed financial assets, the number of daily open market operations increased to 440,000. See *Jornal do Brasil,* January 29, 1990. Banco Itau, the second largest private bank in Brazil, averaged in 1989 on a daily basis 634,000 open market operations daily, and processed 10.4 million documents, 7.6 million on−line transactions, 5.6 million deposits, and 4.2 million checks. The volume and intensity of transactions in 1989 required a rapid expansion of Itau's automation and communication systems, and doubling of its data processing capabilities. See *Jornal do Brasil,* February 1, 1990.

15. Between 1965 (the year of the Banking Reform Act) and 1975, the four−bank asset concentration ratio (excluding public sector banks) climbed from 17 percent to 41.1 percent, and for the 20 largest banks, the ratio climbed from 51.2 percent to 89.2 percent. During the same period, the total number of banks decreased from 320 to 106. See *"Relatorio da Comissão Especial de Automção Bancaria," Secretaria Especial de Informatica,* MCT, 1985, pp. 103 and 119.

16. See *"Relatorio da Comissão Especial de Automação Bancaria," Secretaria Especial de Informatica,* MCT, 1985, pp. 104−5.

17. According to the National Center of Banking Automation (part of the National Federation of Brazilian Banks).

18. In fact, whole systems and branch subsystems have already been exported to Latin America (Venezuela, Argentina, and Paraguay) where banking is organized within a transaction environment similar to that of Brazil. Further, a $20−$30 million contract with Hungary was waiting to be finalized by the end of 1988, which was dependent on countertrade arrangements.

19. In 1988, there are fewer than 2,000 on−line branches (out of 15,000)—most of them in metropolitan areas and belonging to the larger banks. The banks with the largest proportion of on−line branches are those with subsidiaries in the automation business, such as Banco Itau (half of its approximately 900 branches are on−line) and Bradesco (with one−third of its nearly 2,000 branches online). The domestic market continues, therefore, to be quite large, although automation needs are now mostly concentrated in smaller branches, except in the case of Banco Real (with no agency on−line), Banco do Brasil (of nearly 3,500 branches, fewer than 100 are on line), Banorte, BCN, and some of the mid−size banks.

20. Cash dispensers are a relatively new product, first deliveries having taken place at the end of 1987. At the end of 1988, fewer than 500 units were sold, but the in−and out−branch market (on firms' premises, for example) is potentially large.

21. These figures were obtained directly from the networks and appear to be more reliable than the reported total (in Table 13.8) of 862 ATMs at the end of 1987. In either case, the ATM installed base is quite small, being less than 1 percent of the U.S. base. By mid−1987, the 100 largest U.S. networks had a total of 68,000 ATMs and 40,000 point−of−sales cash dispensers. See *Bank Network News,* September 1987.

22. Itautec is currently planning to enter into a joint venture (possibly with Sonae, a retail chain) to assemble (initially CKD and thereafter SKD) and sell its point−of−sales terminals.

23. Although estimates of minimum efficient scales tend to be imprecise, it is telling that Samsung Electronics Co. announced in 1988 that it had opened a $12 million plant with an initial capacity of 400K color television sets and the same number of chassis per year in Tijuana, and that it would invest an additional $2 million to increase its capacity to 600K sets a year in 1990, with most of its output going to the United States and Latin America. Samsung, incidentally, has other plants in Portugal, the United Kingdom, and the United States, and is planning to set up plants in Thailand, the People's Republic of China (PRC), Hungary, and Spain, to avert tariff barriers.

24. Springer National is one color television producer that has taken important steps to improve production technology. It introduced three sophisticated automatic insertion machines, and to achieve greater precision in machine processing, it instructed its subcontractors to manufacture printed circuit boards without any warps and with errors of less than 0.1 mm for the distances between insertion holes. Furthermore, the firm's testing and inspection technology is based on automatic testing systems.

25. High production costs are also due to elevated inventory expenses associated with the considerable time it takes to move parts and components from São Paulo to Manaus, and with environmental difficulties (high humidity and soil acidity) that require special packaging and additional labor for material maintenance.

26. In surface−mount assembly, electronic components are mounted directly on the surface of substrates with no leads inserted through the surface. For this mason, the technology for surface−mount assembly is ideally suited for automatic assembly. A whole new range of devices (miniature components) have been developed for surface mount: resistors, capacitors, diodes, transistors, ICs, and even chip carriers.

27. It is noteworthy that locally−produced picture tubes cost $80−$100, whereas international prices for equivalent models range from $60−$80. Two producers are en−

gaged in their manufacture: Philips and RCA—the former through a fully−integrated plant with a capacity of 1.2 million units per year, and the latter through a semi−integrated plant with 0.8 million units per year capacity.

28. Law 4117 enacted in 1962 oriented the federal government toward promoting the development of the telecommunications equipment industry by stimulating entry and growth of national firms, and establishing and approving technical norms and specifications for the equipment to be used in telecommunications services. The basic instrument to carry out these objectives was TELEBRAS procurement policy as defined by ministerial directives 661/75 and 662/78. Policy implementation was to be supported by GEICOM (the Interministerial Group for Components and Materials), created in 1975 to increase domestic content, establish programs for technology transfer and development, and to standardize the production of equipment, component, and materials, and supported by CPqD (the Research and Development Center of TELEBRAS), started in 1976 (see a brief history and description of CPqD's activities below).

29. Between 1976 and 1985, exports of telecommunications equipment averaged $26 million.

30. See the description of this early period in Helio M. Graciosa, "Telecommunications Research and Development in Brazil," mimeo, 1988. According to the author, the sponsored R&D program areas were antennas and microwave radio propagation (at Rio de Janeiro's Catholic University), fiber optic communications, semiconductor lasers, voice signal digital encoding and time−division multiplexing (at the State University of Campinas), digital switching at the University of São Paulo, and microwave radio propagation (at the Instituto Tecnologico da Aeronautica (ITA)). In 1975 one firm was contracted to develop a Cassegrain−type, 10−meter parabolic antenna for satellite communications and another to develop a push−button telephone set (pp. 4−5).

31. See TELEBRAS, "The TELEBRAS Research and Development Center," undated.

32. CPqD also offers laboratory infrastructure, specialized pilot production lines, and a data processing network, as well as a technical data bank necessary for manufacturing.

33. In this regard, CPqD's experience is broadly in line with the notion borne out of many cross−country studies of technology development and transfer that suggest that technology, instead of being regarded as public information, might be more usefully conceptualized as a quantum of knowledge retained by individual teams of specialized personnel. The key to successful absorption would therefore be the development of a skilled labor force with hands−on development experience. See N. Rosenberg and C. Frischtak, *International Technology Transfer: Concepts, Measures and Comparisons*, Praeger, 1985.

34. As a senior CPqD officer put it: "when we started everything was incipient. . .we couldn't afford to concentrate just on switching."

35. According to M. Graciosa, *op. cit.*, "R&D activities in the area of time−division electronic switching started in 1973 when a team from the University of São Paulo [w]as contracted to develop a laboratory prototype of a time−division stored program controlled (SPC) telephone switching system. Such goal was achieved by 1976 . . . . In the first half of 1977, soon after CPqD was founded, most researchers moved to the Center and started working out the development of a whole family of time−division SPC telephone switching equipment named Tropico" (p. 9).

36. An innovative degradation concept in the presence of faults makes Tropico tolerant to multiple faults in its control part, penalizing the system by decreasing the quality of service; in similar circumstances in other systems, however, it would lead to the interruption of services.

37. It is noteworthy that even export−driven economies, such as those of Japan and Korea, used their domestic markets as technological staging grounds for export penetration. There are few cases of products being internationally competitive from the time of start−up. A careful examination often shows, however, that domestic market activities were responsible for generating the needed technical base. A classic case is that of the Korean shipbuilding industry, the capabilities of which (in areas such as soldering of large metal pieces, or in production planning and organization) can be traced to the experience acquired by producers in heavy construction.

14— The Electronics Industry in India: Past Problems, Recent Progress, Future Outlook

Geoffrey Gowen and Daniel Hefler

The Indian electronics industry, established more than 25 years ago, is still a small part of the international industry, and accounted for around 0.7 percent of international electronics production in 1989. Relatively stagnant during the 1970s with a growth rate of 10 percent in real terms, the Indian electronics industry was the victim of a policy regime dating back to the early days of independence that emphasized self−sufficiency and reliance on indigenous technology. These policies began to change at the beginning of the 1990s, and the industry, as a result, has begun to catch up: its growth rate accelerated to 18 percent in the first half of the 1980s and to nearly 26 percent during the Seventh Five−Year Plan period (1984/85−1989/90).[1] Gross output reached a level of Rs 92.0 billion (US$6.2 billion) in 1990. The electronics industry now comprises 7−8 percent of manufacturing value added. Its growth has recently stagnated due largely to foreign exchange constraints on imported inputs and to decreased investor confidence; growth will no doubt resume, however, with the return of political stability. What is the outlook for this industry in the light of these changes in policy and the constraints that still exist? This chapter tries to address this question.

The subsector is relatively domestically oriented. Total exports in 1990 reached only Rs 9.3 billion (US$531 million), averaging about 9 percent of output, of which 35 percent originated from free trade zones. Except for the People's Republic of China (PRC), this share is lower than for other developing countries that have significant electronics subsectors. Imports meet only 25−30 percent of the demand for final products. However, except for such traditional consumer goods as radio receivers and black−and−white television sets, whose inputs are mostly produced locally, the subsector imports at least half the required materials and components.

Public sector enterprises (PSEs) account for about 35 percent of the subsector's output, ranging from 10 percent in consumer goods to nearly 100 percent in communications, aerospace, and defense. Most of the 3,000 or so electronics firms are small−scale industries (SSIs), which produce about 30 percent of total output and are especially important in consumer electronics. Medium−sized and large private enterprises account for about 35 percent of total output; many of the large private firms have had long−standing associations with multinationals.[2]

Expansion in consumer electronics, particularly in color television, has helped to accelerate the subsector's recent growth. This segment now accounts for about 34 percent of total electronics output. Although the production of data processing equipment has grown rapidly because of government−sponsored modernization programs in industry and in banking, output in this segment only reached about 96,000 units in 1990 (mostly microcomputers), representing about 9 percent of India's electronics subsector compared with a more than 20 percent share in other countries. The industrial, telecommunications, and components segments each command 15−17 percent of the subsector's total output. In telecommunications, two large PSEs dominate: Indian Telephone Industries (ITI) and Hindustan Cables Limited (HCL). Industrial electronics, which includes several large PSEs, is concentrated in industrial process controls and power electronics. In this segment, several firms with international ties have been able to export worldwide.

The structure of the components segment is highly fragmented, with a few large firms at one end and many small producers at the other. Production is largely for use in radio and television sets. Semiconductors (mostly discrete devices) account for only 12 percent of India's components output compared with 30−50 percent in developed countries. SSI and medium−scale industry (MSI) integrated circuits (ICs) are produced by a single PSE, Bharat Electronics Ltd. A second PSE, Semiconductor Complex Ltd., was producing large−scale integrated (LSI) ICs partly from imported wafers until the factory burned down in February 1989, but very large−scale integration (VLSI) ICs have always been imported. In total, locally produced ICs meet less than 10 percent of demand and account for 3 percent of component production compared with a larger share worldwide.

Assessment of Competitiveness

India's electronics subsector developed in an environment that protected it from both domestic and international competition and insulated it from technological progress. Process technologies are generally outmoded (8 to 20 years behind). Product technologies, on the other hand, lag behind in international standards in some areas by only a few months (e.g., some models of microcomputers), but in others are five or more years behind. Regarding prices, a 1986 study showed factory prices (before excise taxes) of the products of 10 major electronics firms exceeded world prices by 20−170 percent and many products were of inferior quality. Though increased domestic competition since then has narrowed the gap somewhat, prices remain high by world standards.

Several important factors account for the high production costs and prices. Production scales are substantially smaller than minimum economic scales (MESs) of leading multinationals by factors of 20 to 100 in some product lines, which affects raw material prices, capacity utilization, and other costs. Indian electronics industries also bear high customs duties on imported components inputs and several other indirect taxes, so that total indirect taxes comprise 20−40 percent of sales prices. Since scales are small, most firms pay 15−40 percent above world prices obtainable through bulk purchases of materials and components. Profit margins for well−operated Indian firms are high by international standards for electronics industries (from 18−40 percent of factory prices), reflecting lower competitive pressures in India. Other factors that hurt competitiveness include the following: (a) India's relative isolation from world markets, which limits exposure to product trends and changing technologies; (b) the related problem of supply uncertainties stemming from reliance on imported raw materials, components, and other needs, as well as delays due to customs administration (all of which result in costly inventories); (c) the lack of suppliers, precision services, and other industrial and service infrastructure of adequate technological capability and reliability; (d) limited and unreliable communications services; and (e) government regulation and controls. In addition, Indian electronics firms face shortages and interruptions of power, communications, and input supply, and they face labor regulations that lead to inflexibility and encourage overstaffing.

Although the subsector is inefficient by world standards, a few firms in India now produce competitively with domestic prices that, if adjusted for indirect taxes and international profit norms, would approach world prices. These firms are typically found in product areas (such as black−and−white televisions) characterized by relatively simple and mature technologies that have been fully assimilated, and by domestic markets large enough to allow economies of scale. In addition, product areas that require a significant level of skilled labor—such as printed circuit boards (PCBs), individual electronics products with a high−design content, and above all, computer software—perform well. In most product areas, however, even the most efficient firms are uneconomic, exhibiting one or more of the following characteristics: (a) production is highly capital intensive; (b) technology is difficult and has not been mastered because of inadequate technology transfer arrangements; (c) the market is too small to allow adequate scale, or else the technology appropriate for the size of the market is obsolete; and (d) high protection allows "kit assembly" from foreign sole−source suppliers with resultant high raw material costs.

Policy Environment

Past Policy Framework

The high prices and variable quality of electronic products have largely been the result of the industrial and trade policies followed until recently. These policies, which were an integral part of the industrial policy framework that emerged in the late 1960s and early 1970s, emphasized self−sufficiency, indigenous technological development with minimal recourse to foreign technology, res−

ervation of key products to the public sector, concessions to small−scale producers, and pressure for the regional dispersion of production. These policies in electronics resulted in a capability to produce many products in each of the electronics segments. However, they imposed major constraints on the development of an efficient electronics subsector:

The industrial licensing system severely regulated entry and restrained growth of the most efficient producers. Larger firms were inhibited from expanding because they were dominant and/or foreign owned (especially in consumer electronics and components).3 Some 24 product areas, including some that needed scale for efficiency, were set aside for SSIs. Exit of inefficient firms was discouraged by a combination of labor regulations, restrictions on asset transfer, and bank lending practices. These policies and procedures, together with those limiting total domestic production capacity to the perceived size of the market, decidedly restrained domestic competition in important product areas. The emphasis on technological self−sufficiency led to backwardness in processes and products. The policy climate discouraged foreign collaborations, and many joint ventures used technology sufficient only to enter production, but not to update thereafter. Restrictions on royalty payments and other limitations did not provide enough incentives to encourage foreign firms to enter joint ventures, especially those firms with proprietary technology in the more sophisticated areas.

The trade and protection policies, which resulted in extremely high levels of effective protection (due to high tariffs and the banning of competing imports), prevented alternative sources of potential competition from developing and discouraged exports, which could have exposed the industry to international trends and competition.

The reservations of some segments to the public sector (telecommunications and defense) eliminated private sector competition and allowed inefficient monopolies to develop.

The high level of indirect taxes contributed to higher production costs, and the complicated structure of these taxes hampered the development of exports because identifying the indirect taxes to be rebated or otherwise offset was difficult.

By encouraging geographic dispersal among India's states,4 government policies hindered concentration of the industry, which was vital to developing a strong supporting infrastructure.

Recent Policy Reforms

The government reaffirmed the importance of the electronics industry—not only for its direct contribution to industrial output and employment, but also as a source of productivity improvements in manufacturing and other sectors—and singled it out in the late 1970s for policy changes to achieve more efficient growth. A series of major policy changes dealing with different electronics segments commenced with the Policy on Electronics Components in 1981, and led up to the Integrated Policy Measures in Electronics (March 1985), which consolidated previous pronouncements and made additional fiscal and licensing reforms. A major reform in computer software followed in December 1986 with the adoption of the Policy on Computer Software Export, Software Development and Training. Incremental improvements have continued to be made since then. Electronics has also benefitted from the series of discrete policy actions initiated since 1985 that apply to all industries, which have cumulatively and significantly improved the environment for industrial policy in general. These reforms have been complemented by some liberalization of the financial sector, especially in capital markets.

Of the general reforms affecting electronics, most important for electronics has been the gradual liberalization of the regulatory system to lift restrictions on entry and enterprise growth. Components and consumer electronics have been specifically delicensed; other electronics segments benefitted from the June 1988 increase in the general licensing minima from Rs 50 million (US$2.5 million) to Rs 150 million (US$7.5 million). For industrial projects generally, delicensing was extended to units importing up to 30 percent of input needs, up from 15 percent in the past. In areas still subject to licensing, more flexibility has been given to adjust both output mix and capacity. Licensing procedures have been simplified. Department of Electronics (DOE) introduced "single point" scrutiny of project applications in computers, and in industrial products in 1984 and computer software in 1986, though with mixed success. Access to imported capital goods for electronics was assured, at least until the beginning of 1990, by placing much of the specialized equipment used by electronics firms on open general license (OGL). Since then, controls imposed by Reserve Bank of India (RBI) have made it difficult for electronic firms to obtain

financing for both capital goods and material inputs. Products reserved for SSI, which included many types of components, have been virtually eliminated.

The product areas open for investment to electronics firms classified as Monopolies and Restrictive Trade Practices Act (MRTP) (which subjects them to different types of anti−monopoly regulation) has expanded from components to include all segments, except for consumer electronics. Electronics benefitted from the 1985 general increase in the threshold level for a firm to be classified as monopolistic.5 Telecommunications, formerly the exclusive preserve of the public sector, was opened in 1984 to the private and joint sector for manufacture of equipment at subscribers premises (that is, telephone handsets, electronic private automatic branch exchange (EPABXs)), and in 1988 was broadened further to include some of the remainder, including rural exchange and transmission equipment (for firms with state ownership of 51 percent or more).

Domestic deregulation has had a major impact on increasing domestic competition in electronics, as evident from the ex factory price drops of 40−80 percent since 1985 in some of the major products, such as color television sets and microcomputers. Pressure on domestic profits as a result of competition has also helped to increase the incentive to export. In parallel with deregulation has come improved access to foreign technology —critical to electronics—which now accounts for 20 percent of foreign collaborations. Restrictions have been lifted on foreign ownership if equity is less than 40 percent. Limitations have also been lifted on the types of technology firms are allowed to import. Foreign collaborations have become more attractive to foreign partners because of the 1987 increase in, the royalty ceiling from 5−8 percent. These measures dramatically increased the number of foreign collaborations, which averaged 170−200 per year in the period 1985−88 compared with 10−15 per year in the mid−1970s. The flow has dropped to less than half these levels since, which reflects macroeconomic difficulties, however, rather than any return to earlier administrative rigidities.

In the area of trade policies, quantitative restrictions (QRs) have been greatly reduced for components, which are now mostly on OGL to actual users and were eliminated entirely in the case of software. The July 1988 action to allow all industrial items classified as "limited permissible" to be purchased under export replenishment license[6] essentially eliminated this as a quantitative restriction to users willing to pay the additional premium, recently at around 25 percent, which accrues to REP license sales. The import duty structure has been largely rationalized, with raw materials generally at 35 percent, processed parts at 50 percent, components and peripherals at 80 percent, and final products ranging from 90−150 percent.

The incentive to export has grown as a result of three factors: (a) overcapacity in a number of products, especially in passive components (carbon film resistors, for example) following deregulation; (b) improvement of export policies and administration, which began in 1986; and (c) the adoption of a more flexible and realistic exchange rate policy leading to a *real effective exchange rate* that depreciated by more than 30 percent from the end of 1985 to the end of 1989, and which has dropped since then in response to the growing foreign exchange crisis precipitated by the Gulf War. In response, exports of electronics products (excluding free zones) which had stagnated by 1984 increased nearly eightfold in dollar terms in the following six years, growing from 2.7 percent of total production in 1984 to 6.6 percent in 1990. With regard to the tax system, the government has reduced and simplified corporate taxes, and implemented a modified value added tax (MODVAT) that eliminates the cascading effect of indirect central government taxes for most products and facilitates indirect tax deduction for exports, and rationalizes tax incentives for small scale industries.

As a result of the pioneering improvements in the electronics policy framework, which began in 1981, and the more recent general policy improvements that date mostly from 1985 onwards, investment has greatly increased, especially from the private and joint sectors. The situation at the end of 1987 was roughly as follows: electronics investment, as measured by the commitments of the two major all−India financial institutions (the Industrial Development Bank of India (IDBI) and the Industrial Credit and Investment Corporation of India (ICICI)), which provide about 80 percent of project financing for medium−sized and large firms in this segment, had increased in the period 1983−85 to more than six times the level of 1977−79 and in 1986/87 to more than double the rate of 1983−85. Moreover, the composition of electronics financing had changed: private and joint sector investment, which was less than half the total commitments of these institutions in 1977−79 was more than 80 percent. These trends continued through the end of 1989. Recently, RBI constraints on credit and access to foreign exchange, together with uncertainty

over long−term economic policies, has greatly diminished investment demand.

Policy Constraints

The policy improvements to date have helped encourage a more efficient industry that has promise, in some areas, of becoming internationally competitive. Despite the improvements discussed above, however, the new policy framework has not gone far enough to ensure that cost competitiveness and quality of Indian electronics products will approach international standards. A study of the electronics sector by the World Bank that was completed in June 1987[7] suggested additional areas for change. Although the suggestions are five years old, they are largely valid today. The study's recommendations included (a) progressively eliminating quantitative restrictions on imports and at the same time gradually reducing customs duties to compel domestic firms to upgrade their products, improve efficiency, and lower prices to meet world price and quality standards; (b) simplifying and eventually eliminating the Phased Manufacturing Program (PMP) which encourages uneconomic levels of indigenous production; (c) eliminating the remaining disincentives that restrict access to foreign technology leaving firms free to choose technologies appropriate for production and market conditions, with minimum government involvement; (d) extending capacity delicensing to industrial electronics, computers and telecommunications; and (e) removing remaining dominant firm (MRTP) clearance requirements for product groups where scale is needed for efficiency.

The study also emphasized the need for an easement of exit restrictions to complement the measures taken to improve entry. While recognizing that changes for this purpose are needed in banking, labor regulations, and bankruptcy procedures that go well beyond the electronics industry, the study suggested that the electronics industry might be selected for priority treatment. The study underlined the importance in the longer run of extending the MODVAT to a more comprehensive value−added tax system, as well as the need to persuade the states to harmonize state level taxes with the MODVAT system and to eliminate discrimination between local and out−of−state production, which have become an important source of distortion that is fragmenting capacity in this industry. The study also pointed out the need to lift or reduce restrictions on location to allow economies of natural agglomeration to be realized, such as in other areas of the world where the electronics industry has concentrated.

The government continued until the end of 1989 to make incremental changes in the policy environment for this industry, both in the form of broad industrial measures that affect electronics, and measures specifically concerning electronics. These included (a) reducing further delicensing restrictions on dominant firms; (b) raising the threshold on the percentage of imported materials to total materials that subjects a firm to licensing from 15−30 percent; (c) extending delicensing to microcomputers, peripherals, and monitors; (d) rationalizing the tariff structure for computers and computer peripherals; (e) reducing the indigenization objectives of the phased manufacturing program from 90−70 percent; and (f) eliminating quantitative restrictions (QRs) on a broad range of products for firms willing to pay an additional premium.[8] A new industrial policy announced in May 1990 would have made major additional changes;[9] informed local observers estimated that the changes would eliminate 70 percent of proposals for regulation (from all industries) previously submitted to the Ministry of Industry.

The Basis for Competitiveness

What are the major strengths—and weaknesses—that will influence the directions in which India's electronics industry should evolve? On what bases will its potential competitiveness lie? The following are the major factors that must be considered in making such an assessment:

The large pool of scientific and technically trained manpower. Skilled engineering and technical manpower is widely available at rates that are perhaps one−tenth as high as those in the United States and Western Europe. This is the most important resource on which to base India's medium−and long−term competitive advantage. This resource is constrained, however, by lack of training and experience that deserves—and is now beginning to get—highest priority.

India's large population and potentially vast domestic market. India's population has reached more than 800 million and, though a large proportion subsist below recognized standards that define poverty, the purchasing power of the remainder already allows production at an economic scale of many consumer and industrial items—production that would not be economic in most developing countries of comparable income levels. Its markets for most

electronics products, however, are small by international standards: they are less than those of upper middle−income newly industrialized countries (NICs), such as Turkey or the Republic of Korea, which have one−twentieth the population.[10]

An industrial base, including a long−standing electronics industry with a pool of capable and experienced managers, that is relatively larger than that of most other developing countries. Managers of multinational firms with worldwide experience continually stress how impressed they are with the intelligence, dynamism, and flexibility of the managers and entrepreneurs that they meet in India. The industrial base and its management, however, has evolved over many years under a highly protective policy environment that, until recently, tended to stifle competition and allowed survival (indeed, prevented exit), despite outmoded or even obsolete technical processes, and limited scales of operations and fostered inefficient managerial practices. This legacy cannot be dispelled overnight.

The large pool of nonresident Indians (NRIs). Many are based in the United States and have key technical and managerial roles in the U.S. electronics industry. They can open pathways to potential collaboration arrangements, and many of them control technical and financial resources that they can invest themselves. They are major potential agents for technology transfer and upgrading, but few have returned to India.

India's unskilled and semi−skilled labor, which is widely available at a wage differential that is nearly as great as that for skilled manpower, is now relatively unimportant for the electronics industry because electronics process technology has become so capital intensive. Because of the extremely high value−to−weight ratio of basic electronics products, such as transistors and integrated circuits, manufacturers, particularly U.S. manufacturers, chose in the past to direct to low−wage areas those processes that made heavy use of semi−skilled labor, such as assembly and packaging. The increasing degree of automation required for achieving precision and quality under the more exacting requirements of the new technologies, however, is leaving relatively few products or processes that are semi−skilled and labor intensive. Moreover, compared with labor in most other countries in South and East Asia, unskilled and semi−skilled labor in India has displayed a rigidity of work practice and lack of discipline, such as is evidenced in high manning schedules, a high level of work stoppages, and frequent absenteeism, that is especially pronounced in large−scale, unionized factories, all of which lead to low worker productivity.

In addition to the constraints noted above, factors that limit the potential competitiveness of electronics including the following:

India's relative isolation from world markets, which limits exposure to product trends and changing technologies.

The closely related problem of supply uncertainties stemming from distant sourcing of imported raw materials and other needed inputs, as well as from delays due to customs administration and import licensing.

The lack of suppliers, services, and other industrial infrastructure of adequate technological capability and reliability, due not only to the small size of the industry, but also to its geographic dispersion, which licensing and other policies have deliberately fostered.

A heavy governmental administrative structure concerned with industry, despite a strong commitment by some policymakers to remove the long−standing constraints to industry's development. These government structures evolved in the era of regulation and physical control and are therefore not well adapted to a more liberal environment based on fiscal controls.

In addition, the international environment, in which prices continue to fall relentlessly, accompanied by continuous rapid technological advancement, makes "catching up" extremely difficult.

Guidelines for Establishing Potential Competitiveness

On the basis of the above strengths and weaknesses, a number of principles can help to distinguish—at least in broad terms—between the product groups in which competitiveness is possible or likely and those for which establishment or further expansion is likely to be costly. Some of these principles are "policy sensitive," that is, their importance can be affected by changes in the policy environment and will evolve over time as market conditions change. In total, they help to provide a strategic view of how the industry could reasonably be expected to evolve over the next five to eight years.

Technical Difficulty and Related Factors

A first critical principle is that some products have relatively little near−term potential because

technical difficulty and related factors make local production extremely difficult and potentially costly. A system of classifying electronics products into four levels is developed in Table 14.1. The table characterizes each level in terms of the degree of technical difficulty of production, the type of assistance likely to be required by Indian entrepreneurs, the importance of an adequate electronics infrastructure, and other factors. Products of the fourth group, "very high level of technical difficulty," include items like VLSI (16−bit and more) microprocessors and state−of−the−art mainframe computers. These products are characterized by the following: fast−changing technology, the difficulty in gaining access to the technology because of its proprietary nature, and the likelihood that a lack of industrial infrastructure (precision machining and molding, plating, surface treatment, hermetic sealing, art work), as well as engineering and design services, would have a severe impact on potential costs and quality. Attempting to produce products commercially in the high−technology group in the medium term would not be advisable.11

Products in the third group (high level of difficulty) can be considered for manufacture in India and should be viewed as the "leading edge." Local manufacture is desirable because of the importance (in most cases) of mastering the technologies to allow further evolution and the opportunity provided for developing and using skilled technical manpower. Furthermore, international demand for products in this group tends to be growing faster than for products at low and moderate levels, which are typically more mature. However, simply because a product is in the high level of difficulty group does not automatically mean it should be manufactured in India. For other reasons discussed below, such as the small size of domestic markets, local manufacture may be extremely costly.

Scale and Domestic Market

Many product groups have little potential for efficient production until the prospective domestic market is likely to permit plants of adequate scale. Insufficient scale can result in high costs because equipment appropriate to produce at the levels of quality and efficiency is not fully utilized. This is insufficient scale in a technological or engineering sense and is important principally for the components and raw materials segments. Products in these segments are generally standardized, and production processes tend to be relatively capital intensive. One of the major defects of Indian electronics policy has been that high protection and regulatory controls—SSI reservations, licensing restrictions on capacity expansion, and limitations on size and market share through MRTP and Foreign Exchange Regulation Act (FERA) legislation—have allowed plants below minimum technological scale to be established and to continue to exist. Deregulation and the resulting unrestricted entry, without reduction of customs tariffs and QRs, has not cured this because of difficulties in exit, despite increased domestic competition.

Scale minima for India, summarized in Table 14.2, were developed in 1987 for a sample of products, mostly in the components segment. Based essentially on the judgments of experienced industry consultants rather than on detailed cost calculations, they reflect minimum scales required in the technological sense to ensure efficient use of the equipment. They provide useful guidelines for identifying products as premature for domestic production, unless there are strong justifications, such as the possibility of exporting. For some product groups (especially in consumer electronics), these minima are well below "world scales," which generally reflect organizational considerations that go beyond technical requirements at the plant level. For such product groups, however, the minima would be a useful intermediate step that is above present scale levels for most enterprises. The introduction of scale minima by the government in 1986, to prevent the establishment of undersized firms in the deregulated but still highly protected domestic markets, is justified for products in which process technology is relatively mature, at least for an interim period, until a more internationally competitive environment can be achieved through the systematic reduction of trade barriers.

For some product groups, particularly in industrial electronics, data processing, and telecommunications, *a priori* scale minima must be used with caution because the processes used to make individual products vary so widely. At one end of the scale, one can find homogeneous products that are now mass produced—for example, microcomputers or standard telephone sets—in which scale considerations may be important (and in which India's competitive advantage, as discussed below, may be limited compared with that of East Asia). At the other end of the scale are niche markets in which a special design edge, software skills, or even packaging and marketing skills differentiate a product and allow nonautomated production in low volumes. With such products, advantages of large scale are offset by the need for flexibility in design and production. Many such products, especially in

Table 14.1
Classification of Levels of Technological Difficulty for Efficient Electronics Products Production in India

Level of technical difficulty	*Likely type of assistance required for Indian entrepreneurs*	*Availability of technology*	*Does lack of industrial infrastructure eliminate serious consideration on economic grounds?*	*Likely medium−term technical suitability for production in India*	*Product group examples*
Low	None to minimal.	Readily available either embodied in purchase of equipment, through licensing, or (more expensive) through initial period of purchase of parts and materials.a	No.	No problem.	Radios, black and white TV assembly, most passive components, single−sided PCB for consumer products.
Moderate	Assistance with plant installation and start−up.	Generally available, but usually under licensing or know−how agreement;	No, but may impose higher costs on Indian projects.	No problem, but suitable technology source important.	Color TV assembly, color TV tubes, analog process controls, microcomputers, printers,

		sometimes (more expensive) through initial period of purchase of parts and materials, a Costs at moderate level likely to be more expensive than low (above).			subscriber sets, simple discrete transistors, professional PCBs (up to four levels).
High	Close collaboration with technology source for installation start−up, and prolonged operation to ensure effective transfer of technology and access to new technical developments.	Technology mostly available from primary source and likely to be extremely expensive unless obtained on a joint venture basis.	No, but imposes much higher costs on Indian projects; thus could affect viability in medium term.	Close technical collaboration usually critical; does not necessarily ensure economic viability.	VCR (with tape deck and magnetic head), digital process controllers, minicomputer, EPABX, PCB (more than four−layer), linear IC for consumer products.
Very high	Same as high (above), but much higher requirement for technical and R&D capability in order to assimilate and stay abreast of changes.	Technology is only available from primary sources and likely to be closely held and almost impossible to obtain except on joint venture basis with controlling interest for foreign firm.	Yes, general level of technical services and specialized services not likely to be adequate in the medium term regardless of effort.	Not likely to be technically suitable; attempts to undertake likely to be very costly, Justifiable only on basis of security or national defense.	Integrated circuit tester, state−of−art mainframe computers, VLSI microprocessor (16−bit and above), fiber optic transmission.

a . Initial purchase of parts and materials means that the foreign supplier provides technology and training in exchange for the exclusive right to supply all parts and materials for a specified time, usually at least one year, and often considerably longer. This, which is similar to kit assembly, is usually an expensive, though convenient, method of technology acquisition.

Table 14.2
Scale Standards for India's Electronics Industry

Product component	*World scale*	*DOE/government minima as of May 1986*	*Suggested scale for India*
Television sets, color	1,000,000−2,000,000	50,000 (SSI) 100,000 (organized)	200,000
VCR without tape deck and head	100,000	50,000	50,000
VCR with tape deck and head	1,000,000	300,000	500,000
CRT, color and black and white	1,500,000−2,000,000	500,000(black and white) 1,000,000 (color)	1,000,000
EPFAX	100,000 (20,000 for firms using C−DOT technology)	50,000	50,000
ICs (bipolar) SSI/MSI			
without wafer fab	50,000,000	30,000,000	50,000,000
with wafer fab	600,000,000		200,000,000
ICs (MDs) LSI/VLSI			
without wafer fab	500,000,000	4,500,000 for assembly	50,000,000
with wafer fab	200,000,000	and test	200,000,000
PCBs DBL sided (sq mts)	20,000	20,000	20,000
Film resistors	1,000,000,000	100,000,000 to 200,000,000	300,000,000
Film capacitors	500,000,000	50,000,000	50,000,000
Electrolytic caps	100,000,000	75,000,000	75,000,000
Tantalum caps	500,000,000	<10,000,000	100,000,000
Ceramic caps (disk)	5,000,000,000	500,000,000	500,000,000
		(50 million existing; but not recommending investment in the 100,000,000 but expected to go up)	
Multilayer ceramic	1,000,000,000	200,000,000	200,000,000
Soft ferrites (tons)	n.a.	500	500

Hard ferrites	n.a.	n.a.	1,000

n.a. Not available.

Notes: Television sets: assumes axial leaded component insertion, in−circuit testing, and two−shift operation; VCRs: world scale is based on second−tier Japanese firms that subcontract most of the mechanical components and always purchase the heads; CRT: world scale based on industry norm of 1,750,000 tubes per facility; EPABX: world scale based on niche supplier levels; ICs SSI/MSI: are commodity (jelly bean) technologies, minimum scale for wafer fabrication dictates project scale; ICs I. SI/VLSI: demands higher scale to ensure acceptable yields; ceramic capacitors (disc): a dying technology, further investment should be monitored to avoid overcapacity; multilayer ceramic capacitors: production should be encouraged.

industrial electronics, probably have competitive potential, even for exports.

Domestic and Export Markets

Though the Indian market is not large by international standards, it must remain the principal arena for Indian production in the medium term. In other words, given the market's constraints, it is unrealistic to expect that changes in the industry's efficiency, as well as in the policy and infrastructure environment, would permit a shift to an ex−port−led strategy. Elsewhere such a strategy has been initiated by trying to attract international electronics firms to undertake offshore production or processing based on the availability of inexpensive semi−skilled labor or (increasingly) skilled labor. However, worldwide trends do not support such a move. In chip assembly, which has been the most important product manufacturing process sourced offshore, increasing automation in bonding and assembly has reduced the importance of the labor component in manufacturing. Moreover, other costs of foreign operations, for example, the need to hold inventories of complex parts, will increase as chips become more complex and expensive, making assembly abroad less attractive. It is true that some developments continue to favor the use of offshore facilities. The decreasing product life and the trend toward custom and semi−custom chips led to production on a smaller scale, favoring technologies that do not require large fixed investments and the use of less automated equipment. These developments, however, simply ensure that existing successful NIE electronics producers, such as Singapore, Malaysia, and Korea, will continue to have a role as offshore suppliers; they do not ensure that another low−wage country will be able to establish itself as a low−cost supplier of electronics.12 Furthermore, trade in electronics appears to be especially volatile, subjecting investment to high risk whenever it looks only to export markets. Nevertheless, India clearly has the potential to increase exports as changes in the policy and infrastructure environment improve efficiency and the returns to export. Future increases could come more from the domestic tariff area (DTA) than from the specialized export processing zones, even though new ones are now being added.13 Exports (apart from software) as a percentage of production, now around 9−10 percent, might reach 13−18 percent in the next 6−8 years. This would imply fast growth in absolute terms because domestic production will continue to grow rapidly−though not at the pace of the 1980s—because consumer electronics growth cannot remain as strong as engineer growth.

What all this means when trying to evaluate which products make sense for production in India is that judgments about whether markets will allow operation at a reasonable scale must consider primarily domestic markets. Viewing world markets as a way of generating the scale needed, without fundamental change in policies, is premature. In individual segments—especially industrial electronics, which includes product groups that have long−term competitive advantages—this general approach needs to take export possibilities into account. At the same time, it is the domestic market expectations—not the international market expectations—that must govern an evaluation of each product group or segment. Thus, black−and−white televisions, for example, though a declining product in developed countries, are still in a growth phase in India. In the longer term, however, worldwide market trends rooted largely in technology advances will inevitably influence Indian markets and must therefore be considered and monitored. For this reason, one should give more favorable considerations to product groups for which markets are rapidly expanding worldwide (all other things being equal) than to those for which market expansion is slow, stagnant, or declining.

A critical consideration influencing our view of which product groups are most promising is the following: the most important benefits of having an electronics industry, especially on the industrial side, is the potential impact on subsequent users. Economic research continues to confirm what many policymakers often fail to understand: the economic returns from *the dissemination* of information processing technologies and communications are multiples of the price of the hardware.[14] Thus strong pressure from industrialists and technocrats in developing countries and regions to establish local production when it becomes technically feasible to do so, regardless of economic costs, should be resisted because the establishment of uneconomic local production is doubly costly: domestic resources may be wastefully used, and higher prices to end users can retard dissemination and thus lessen the benefits from usage.

The most promising product groups in India are those that make intensive use of high−level technical and engineering manpower, or that lead to its intensive use in subsequent electronic segment activities. Electronics, though becoming increasingly automated, is still a highly skill−intensive industry. Products can require high−level skilled manpower in product design, especially if high levels of research and development (R&D) are normally required for long−term competitiveness, and if there is a high degree of contact between manufacturer and customer in product development. High−level skills can also be important in production, quality control, sales, and after−sales service. Even when manufacture or assembly involves limited skilled input relative to the value of the final product, a product may require high−level technical skills in assessing need, system design, installation, maintenance, and upgrading. The segments that offer the greatest promise from this standpoint are industrial electronics, computers, and, above all, computer software.

Computer software, though still a tiny industry (estimated production in 1989/90 was about US$277 million), is particularly promising because of its high degree of skill intensity. Exports that had reached US$54 million in 1987 had about doubled to US$110 million by 1989. Though the industry is dominated by two firms, which account for about 60 percent of total exports, dozens of smaller firms can contribute to both domestic production and exports. They are constrained by lack of access to marketing expertise, to software productivity tools and hardware needed for software development, and to risk capital to finance the costs of product development and marketing. There is a more generalized constraint to sector growth that applies both to small and large firms: lack of specially trained manpower, as discussed above.

Other Positive Criteria

Several other characteristics can have a positive impact on competitiveness, for instance, transport costs. Although electronics products as a group have a high value−to−weight ratio compared with that of other industrial products, the costs of shipping (including packaging) are significant in a few instances (for example, glass shells for television or cathode ray tubes (CRTs)) and enhance the attractiveness of production for local markets. Another consideration is local availability of critical inputs and experience at competitive prices, which creates economies of scope. This criterion becomes increasingly important as the industry becomes more integrated. It is already significant for a number of products. Computer monitors, for example, can be competitive because of the skill and scale that have been developed by the black−and−white CRT industry.

Product groups whose production process is capital intensive, especially if efficient production requires relatively large production units, tend to be less competitive in India. This reflects our judgment that capital costs tend to be higher for Indian products than for competing imports because of the relatively high costs of fixed assets due to delays in project start−up and implementation. Moreover, large production units generally agreed to be more susceptible to labor difficulties and to problems of regulation and control by government (especially if subject to MRTP constraints) that inhibit their flexibility and hence their ability to compete. These criteria are partly a function of policy and therefore might gradually be changed. Highly materials−intensive processes (such as low value−added assembly) have also been negatively evaluated—other things being equal—because of the high costs of carrying inventories due to delays and supply uncertainties that are frequently encountered in India. As indigenization programs, such as the PMP, proceed, such product groups are particularly penalized as long as domestic supplies remain costly. Additional reasons are the high costs of short−term capital and the rationing of working capital loans in India compared with those of more developed countries. This criterion, too, is partly a function of policy and can be changed over time. Consumer electronics and components contain many product groups that reflect the above characteristics.

Additional Strategic Considerations

In addition to direct, net economic benefits, the development of selected product groups will affect the entire electronics industry. For instance, the size of demand and the existence of linkages will affect the demand for electronics components (as in the case of color television assembly). Products that use important technologies will develop skills and capabilities and will hasten the industry's evolution and upgrading (such as with multilayer chip capacitors). Strategic considerations may justify special policy measures, such as relaxation of limitations on foreign ownership or size. For cases in which the potential learning benefits are high (as with computers and industrial products which have a high degree of skilled manpower usage downstream) and in which the cost curve relating to scale is relatively shallow, promoting the establishment of projects may be justified before mini−mum−scale is reached.

Strategic Overview: A Summary

The outline of an overall strategy for the electronics industry in India emerges from the principles just discussed. Increasing automation in electronics worldwide has greatly diminished the advantage and potential for India to become a new, low−wage processor or supplier of standardized electronics goods. Moreover, India's advantages as

an exporter are undercut by the general problems of achieving manufacturing efficiency discussed earlier. These constraints will require time to change. However, expansion of exports is important for the experience to be gained, and it can be encouraged, especially in the professional sectors that have many specialized products that require significant inputs of skilled labor. But exports will be constrained by the need for foreign collaboration for technology and marketing and (in the case of software, which is particularly promising) by a shortage of technical manpower with the specific skills and experience needed. When compared with total production, therefore, exports are likely to remain marginal and cannot be the primary basis for an expansion strategy.

The focus of the industry's development will therefore be on domestic markets, but that focus must be realistic in assessing the market's potential. India's markets are based on a large population, but they are not large by international standards. Large electronics markets are primarily a phenomenon of higher−income countries that can pay for the precision they provide and for the infrastructure they require. A strategy to try to manufacture in India everything that may be technically possible—the strategy that seems implied by current indigenization policies—could lead to accelerated growth for a while, but will ultimately be self−defeating. The high−cost industry created with little capability for export or keeping up with technical change will eventually be as dependent upon imports as it is now.

The strategy for the industry must also bear in mind that the dissemination of information processing technologies and communications facilities in a developed economy have high economic and social returns. These technologies are products of the segments in which India has possibilities for being competitive. The benefits of these technologies, however, are reduced if their dissemination is inhibited by high costs of hardware and equipment.

Given these considerations, the most important objective for electronics in India in the medium term would be to contribute to the modernization of the industrial sector and the economy at large by providing to downstream industries and service sectors the goods and services that the industry can produce at reasonable costs and prices, that is, in the areas where it can be competitive. The goods and services principally referred to are produced in the three professional sectors: (a) industrial electronics, (b) computers and data processing (including software), and (c) telecommunications. Potential competitiveness in these segments is based upon their requirements for skilled manpower in design and downstream in sales, maintenance, systems design and installation, and on the fact that they tend to be penalized less by the difficult industrial environment than other types of activities. This reflects that most segments are less capital and raw materials intensive and, that with some exceptions, their production is not characterized by high volumes and large scales. Given that the industry plays the above role effectively, it would also contribute indirectly to export growth through modernizing and upgrading the quality of Indian manufactured goods with export markets (for example, machine tools to be modernized with numerical controls). Achieving these objectives should not be jeopardized by trying to force the industry to save foreign exchange by premature import substitution.

A second objective for the electronics industry is to continue to meet the domestic demand for consumer goods that can be produced efficiently in India (for example, radios and televisions). Domestic demand will support production on a reasonable scale of a number of major consumer items (radios and black−and−white and color televisions), with possibilities for export to other developing countries for some products at the lower end of the technology scale, which producers in more developed countries are phasing out. Efficient production tends to require large scale and is materials intensive, however, which somewhat limits the range of products with potential for production in India. Expansion of consumer electronics would also have a substantial impact on the development of the components segment.

To meet these objectives, the electronics industry requires a wide range of electronics materials, as well as passive and active components at a competitive price and quality. The strategy for the industry should therefore ensure that domestic production of these items is competitive. Many types of passive components, especially for consumer electronics, can now be produced in India economically, both because of the size of the markets and because, as mature products, their technology is neither difficult nor fast−changing. However, many inefficient producers exist. Because production is relatively capital intensive and requires little skilled labor, the potential benefits are limited and do not justify substantial protection.

With regard to active components, the simpler types of devices can be produced locally, but they have similar characteristics to passive components. In the critical area of IC production, particularly at high levels of technical difficulty, such as VLSI

chips, Indian producers face the same difficulties as for high−technology professional electronics products: closely held, fast−changing technologies, and a requirement for a high level of R&D capability which in turn requires the availability of high−technology supporting services, and increasingly costly investment due to rising scales and capital intensiveness. Rebuilding Semi−Conductors Limited to produce LSI or VLSI commodity chips therefore makes little sense because for many types of active components, both production and process technology are so demanding and fast−changing that, given present levels of industry development and infrastructure, efficient local production is not a realistic possibility in the medium term. There may be a potential, however, for fostering custom and semi−custom chip production to provide a focus for intensive local software development for chip design.

Notes

1. The fiscal year in India for both government and private enterprises runs from April 1 to March 31.

2. These estimates are based on data from the mid−1980s, but are not believed to have altered significantly since.

3. Firms subject to regulation because of their dominance are usually referred to in India as Monopolies and Restrictive Trade Practices Act (MRTP) firms. Firms subject to regulation because of foreign ownership are usually referred to as Foreign Exchange Regulation Act (FERA) firms, referring to the Foreign Exchange Regulation Act that established more restrictive regulation of firms with more than 40 percent foreign ownership.

4. India includes 19 states plus a number of Union Territories, which are administered centrally, including Delhi, the national capital.

5. The level of a firm's total assets, at which it is considered a monopoly for purposes of Indian regulatory laws, was increased in 1985 from Rs 200 million (US$10 million) to Rs 1 billion (US$50 million).

6. The export replenishment license, or REP license, allows an exporter to retain a certain percentage of net export earnings, which can then be sold to firms referred to as "actual users," which require the product in their manufacturing process.

7. *India: Development of the Electronics Industry. A Sector Report*, Report No. 6781−IN of June 26, 1987 (3 volumes).

8. Products classified as "limited permissible"—that is, imports that may be administratively restricted if the quantity and quality of local production is deemed sufficient—may now be imported by manufacturing firms that require those inputs under a license, which can be purchased from exporting firms, that gives access to foreign exchange. The cost of these licenses varies, but typically runs 15−30 percent of their face value. This means that products in this category can be imported, regardless of local production, with the payment of what amounts to an additional 15−30 percent import tariff.

9. To name some important ones: (a) the delicensing ceiling would have been raised from Rs 50 million to Rs 250 million (Rs 750 million for backward areas), (b) it would have allowed for import of capital goods (CGs) for delicensed investment if less than 30 percent of total investment, and (c) it would also have allowed automatic clearance of direct foreign investment if less than 40 percent of equity and if less than 30 percent of CG was imported.

10. Preliminary analysis suggests that the estimated gross domestic product (GDP) for the portion of total population with per capita GDP above US$750 is a better guide to the relative size of the electronics market than total GDP. For India, this segment is only about 5 percent of the total population.

11. Development of high−speed computers using parallel processing architecture, as is under way at the Center for the Development of Advanced Computing (C−DAC), Pune, may be an exception based on the high degree of design and software input. The focus here should be on developing hardware configuration and computing algorithms suited to problems that need solution under Indian conditions.

12. For additional discussion of trends in offshore production in the semiconductor industry, see Kenneth Flamm, "Internationalization in the Semiconductor Industry," in Grunwald and Flamm, *The Global Factory* (Washington, D.C.: Brookings Institute, 1985).

13. In fact, this is what has been taking place as a result of the recent improvements in incentives to export. Exports from the DTA, which had dropped to 2 percent of total electronics production in 1985, increased to 6.6 percent of production by 1990.

14. See, for example, Timothy J. Bresnahan, "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review* 76, September 1986, pp. 742−55.

15—
Alternative Strategies for Developing Information Industries

Ashoka Mody

The experiences of newly industrialized economies (NIEs), such as those of Brazil, the Republic of Korea, Taiwan (China), India, and Singapore, show a variety of approaches to developing high−technology industries. These economies have in common a relatively developed industrial base, a large stock of educated−manpower, and a commitment to research and development (R&D) and to the promotion of information industries. Each government's policies have, however, varied in important respects, and the resulting achievements have varied significantly. Evidence from successful countries indicates that two factors contribute to rapid growth: product choice and institutional and infrastructural development. Faster growth results from focusing effort on a few products (as opposed to a wide range of information equipment) and through having in place institutions that aid in the application of technology to economic growth.

The term "information industries" typically includes data processing and communications services as well as the electronics hardware that goes into the supply of these services. For most developing countries, the economic benefits are best derived from the use of information technology services (in manufacturing, distribution, and financial services) rather than through the production of hardware. However, the focus of the chapter is on hardware with a limited discussion on design and systems integration services.[1]

Even within the electronics hardware sector, there is much technological diversity. The aim of this chapter is to provide a retrospective on strategies to move up the technological ladder in this fast−moving set of industries. In the late 1970s and through much of the 1980s, it was commonly perceived that the government had a role in promoting technological advancement in specific sectors that were "strategic" or contributed to economic growth through external effects. Such a view has increasingly come under question, not only because of experience with government failures in such attempts, but also because the strategic and external effects from this set of industries are no longer viewed as critical to the growth of most developing economies. In recent years, new entrants on the world market (for example, firms in the southern part of the People's Republic of China (PRC), Northern Mexico, and Thailand) have focused on the lower end of the technology spectrum.

There is evidence that the speed of technology diffusion from advanced to industrializing economies has increased in the past two decades.2 Three factors have contributed to the faster diffusion. First, the technology of information transmission and distribution has improved. Second, the capability to absorb foreign technology has improved. Third, in seeking markets, international firms have been willing to transfer technology to and from alliances with developing economies. Also, increased international competition has forced producers to seek low−cost production sites. In some instances, the transplanted firm has provided exposure to new technologies and has helped to train domestic manpower.

On the other hand, the information industries have costly physical and human investment requirements, and evidence indicates that these requirements are increasing, even at the lower end of the technology spectrum. The theme of government support for electronics, while more subdued than in the past, keeps recurring for this reason. International competition, which leads to a greater availability of technology, also creates the need to learn quickly and price aggressively. Even firms in developed countries have often been unable to cope with these pressures and have sought government support in various ways. The NIEs have similarly tried to overcome entry barriers by enlisting government participation and by appropriate institutional choice.

The essence of the concern in the NIEs and in the developed countries has been whether high technology varies sufficiently from traditional industries to warrant special attention and policies. A complementary issue is whether the traditional concepts of national comparative advantage are relevant for analyzing high−technology industries.

The conclusion of this chapter is that theory does not provide simple prescriptions for the development of information industries. Conventional trade theory tells us that appropriate product choice (reflecting the country's factor endowments) is important for successful growth. And, for the most part, that is borne out by the achievements of the different economies. However, more complex considerations arise from the multifaceted nature of the information industries: their ability, under certain circumstances, to lead the growth of other sectors, the uncertainty characterizing their evolution and the relatively rapid pace of technological change. These characteristics call for the need to develop supporting infrastructure in parallel with the leading sector. They point to the need for appropriate timing of market entry and the need to anticipate the need for capabilities. The complexity is resolved by using multiple policy instruments. The most successful economy in our sample, that of Korea, has used both trade and industrial policy instruments to promote the development of the electronics industry. However, from the less successful economies, we also learn that the choice and use of the appropriate intervention are non−trivial tasks.

International corporations are an alternative to government that is becoming increasingly available. Much development of the newly emerging electronics exporters has been fueled by foreign investors. Thus, the debate no longer need be couched in terms of government action or inaction. It is the substitutability between government and foreign investors, as well as their complementarity, that is likely to interest policymakers in the 1990s.

Industry Characteristics and Comparative Advantage

The case for government involvement in promoting sectoral growth relies on possible externalities that may be associated with that sector. Linkages between sectors of production, leading to pecuniary externalities and possible underinvestment due to uncertainty, have formed the rationale for government support. Even when such conditions prevail, the government is not the only (or even the best) entity to take the initiative. Potentially, international investors are a substitute. As a prelude to discussing these issues, it is helpful to briefly recapitulate the classical view of trade.

Classical Comparative Advantage

According to the classical view, all firms (and countries) have complete knowledge of available technologies and operate with only the most efficient techniques. The location of production determines the range of feasible products and technologies. At each location, a firm faces a set of factor (or resource) prices, which reflect the underlying factor availabilities. Given the factor prices, the firm is hypothesized as choosing products that have a significant requirement of the cheaper factor inputs. Trade takes place between different locations because the differential resource advantages lead to the production of different products. While this is essentially a static theory (and as such says nothing about evolution of the industry), it can be rendered partially dynamic, as in the "stages of growth" approach.3 According to this approach, the pattern of sectoral specialization in a country evolves with its educational and capital stock. The changes in these stocks are treated as exogenous or independent of the development of the industrial sectors being considered.

Linkages

An alternative view emphasizes the linkages between sectors. A widely used concept of linkages refers to the degree to which sectors of production buy and sell from each other. The technological coefficients that determine the extent of buying and selling are assumed to be fixed. If a particular sector buys a large amount of intermediate inputs, it is considered to have large "backward" linkages. If a sector induces the development of downstream industries, it is considered to have significant "forward" linkages. The most important characteristic of information industries, however, is that they change the technological (or input−output) coefficients that link different sectors.4 Nelson has proposed the concept of leading industries, which is germane to the information industries:

Although the fraction of a national value added, employment or capital stock contained in these industries has been quite small throughout the post−war era, these industries have shaped the new products that have emerged and the productivity growth that has been achieved in many other industries,5

Furthermore, Nelson6 has argued that a leading industry is characterized by a strong degree of connectedness. The technologies and components that make up the product or service of the leading industry are closely linked. The importance of connectedness may be even greater when the commonality between technologies and components extends across the leading industries. Unless these underlying technologies and components are available in parallel, the leading industries will not be effective in their "transformative" role.7

Thus, two types of linkages relevant to the information industries have been identified. The group of leading industries is linked to the rest of the economy through its role in creating new products and increasing productivity. In addition, within the group of leading industries, there are technological linkages between components and technologies. The latter linkages are important in understanding the evolution of development of information industries. Unlike the classical comparative advantage view, the linkages view can be interpreted as suggesting that high−technology industries should be developed as part of a broad thrust. Nelson has stated that there is considerable evidence of international flows so that national boundaries are not very meaningful in the development of leading industries. On the other hand, Cohen and Zysman have argued that linkages vary in degree. "Tight" linkages require physical proximity. They point out that a large fraction of service sector output is an input to manufacturing and that such services can only exist close to the manufacturing establishment.8 The importance of agglomeration economies, such as seen in Silicon Valley, also offers support for the argument for colocation.

A leading industry need not be high−technology (in the sense of requiring a heavy expenditure on research and development). Korea and Taiwan (China) have used consumer electronics (particularly televisions) as leading products.9 The television industry has helped the growth of electronics components and has also helped the development of other electronics systems (personal computers (PCs), microwave ovens, and video cassette recorders (VCRs)). All these sectors, in turn, have spawned the growth of an industry to produce capital goods. The development of these subsectors could be interpreted as reflecting the comparative advantage of these countries. However, if they had grown in isolation, rather than as a cluster, they would likely have taken significantly longer to become internationally competitive. The role of the government in this example was essentially to protect and promote the development of the television industry. The growth of the cluster was relatively spontaneous and free of special government incentives or promotion. More recently, as technologically advanced clusters have been built in these two countries, the government intervention has become more detailed. Whereas in the earlier stage, most technology was acquired through reverse engineering of imported products, there is now a greater need to develop technology domestically, creating the need for government subsidies or research institutions.

Uncertainty

A key feature of the information industries has been the uncertainty regarding their evolution.10 The uncertainties are both market−based and technological. Instead of negating the idea of classical comparative advantage, an alternative may be to adopt a portfolio approach. Such an approach can be followed by national planning agencies or large corporations. An explicit portfolio approach has been adopted by Singapore (see Figure 15.1). Industries characterized by moderate to high opportunity and low to moderate risk are considered the most appropriate for Singapore to target or promote. The industries in the top (left−hand) triangle are considered inappropriate and those within the broad diagonal are marginal.11 By itself, uncertainty leads to less focus in choice of industrial sectors than would follow from an adherence to the classical theory of comparative advantage. However, the need for focus becomes important when economies of scale or other forms of cumulative causation are combined with uncertainty.

Uncertainty and Cumulative Causation. Information industries are generally characterized by economies of scale in production and other forms of cumulative advantage. For example, drawing on their research, Teubal et al. (1986, p. 1,401) have concluded the following:

Each generation of product class contributed to subsequent generations of products through the accumulation of a wide variety of intangibles and capabilities; design capabilities derived from R&D; knowledge of markets derived from the actual sale of products; a line−of−products effect and generalized firm reputation.

When the uncertainty is combined with economies of scale, significant learning requirements, or other forms of cumulative causation, an initial accidental

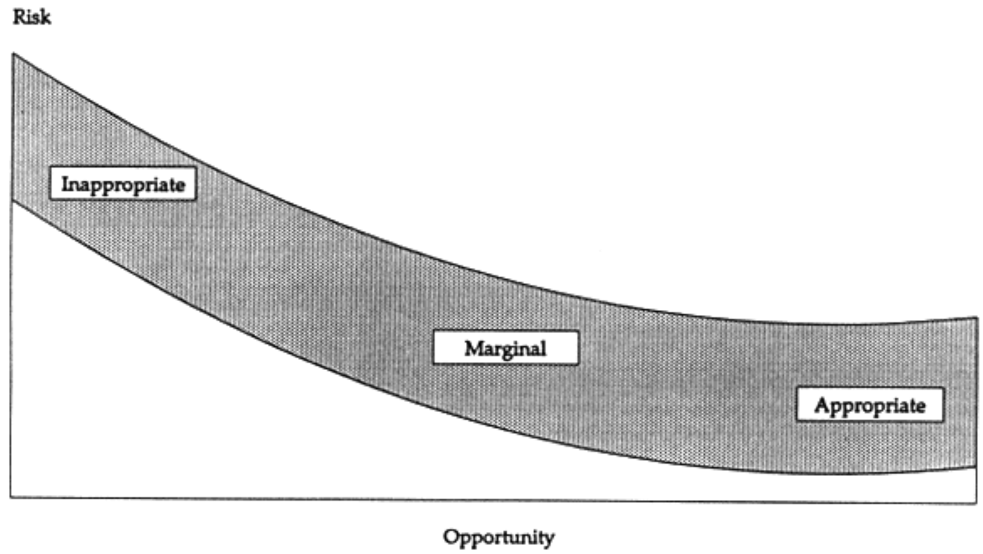

Figure 15.1
Risk and Opportunity in Planning for Information Industries
Source: Government of Singapore.

advantage can turn into a cumulative competitive edge. In an uncertain environment, firms may gain a competitive advantage because of foresight or luck. Trade between countries would then depend to a smaller extent on the resources of the country and to a greater extent on fortuitous factors. In other words, international trade would reflect "arbitrary or temporary advantages resulting from economies of scale or shifting leads in close technological races," leading to an "essentially random division of labor among countries. . . ."12 Selectivity or focus in sectoral development may thus be relevant under circumstances quite different from those assumed by classical comparative advantage theory. While uncertainty suggests the need for diversifying the product range, cumulative causation suggests focus.

Product Cycle and Uncertainty

The above considerations point to the importance of choosing the appropriate time to enter a market. Product cycle theory suggests that when a technology is introduced, the location of production will be close to the location of research and development. As the technology matures, production activity will be transferred to locations with low input prices (provided that the necessary infrastructure is available). In the traditional product cycle theory, new goods are introduced in a developed country. Over time, the technology becomes widely available and competition increases, forcing production to move to low−cost locations.

The length of product cycle in many instances is becoming progressively shorter. As a result, the timing of entry has become even more critical than before. The combination of short cycles and uncertainty creates the need to anticipate the firm's competitive advantage or the country's comparative advantage. A good example of the need to anticipate is provided by Korea's 1984 decision to produce dynamic random access memories (DRAMs). Since wafer processing is a capital−intensive activity.13 and since even now there is little evidence that Korea possesses a static comparative advantage in wafer processing, the rationale for the Korean thrust must be sought in dynamic considerations. But the simple product cycle theory does not apply: Korean efforts in semiconductors are directed toward frontier products and not toward mature products. In 1984 Korean producers began to develop 64K DRAMs, and in late 1985, they began production of 256K DRAMs. Presently, Samsung has the largest share of the global market for 1M DRAMs, and is aiming at capturing the 64Mbit DRAM market from the Japanese when this product is introduced in 1993.14 Although Korea has become the world's third largest producer of chips, given the stiff competition in DRAMs, Korean producers are allocating resources to other semiconductor products that use similar technologies.

It seems clear, therefore, that the Koreans are moving into semiconductor processing, not for reasons of static comparative advantage, nor for reasons suggested by a simple product cycle theory. Rather, these efforts represent an attempt to anticipate their industry's comparative advantage. Since the process of establishing semiconductor facilities, coming down the learning curve, and establishing a critical mass of engineers takes time, starting early is important.

Product Cycle in the Service Sector

Recent research suggests that the product cycle may operate quite differently in the services sector. Drawing on research on local government and the insurance and accounting industries, Barras (1986) has concluded that the product cycle in the services sector operates in the reverse direction. The process of cost rationalizing occurs first, followed by a period of quality improvement and finally by new product introduction. The implications of this analysis are not very encouraging for new entrants. The first phase typically involves high capital investment and labor displacement. The second phase is associated with a move from central computer systems to distributed processing (and local area networks). While this shift does not displace labor, it is usually accompanied by economies in the provision of services and hence encourages "the emergence of financial and business service conglomerates offering a much wider range of different services than hitherto."[15] The third and final stage is emerging and "can only be a matter of speculation at present," but it will require a well−developed telecommunications network as essential infrastructure. Barras has derived no conclusions for the international division of labor, but he definitely implies that barriers to entry are high at each stage and so the transfer of production of information intensive services to developing countries may be more difficult than the transfer of goods production.

Appropriate Institutions to Realize Comparative Advantage

The ability to anticipate and to execute requires capital, human skills, and a sound organization. Michael Porter[16] has noted that how an activity is performed is at least as important as where it is performed. The product cycle theory assumes that the level of technological knowledge is not the same in all countries. Porter goes further and insists that the levels of capability differ between firms and individuals, and even small differences could have significant effects on patterns of trade. Thus to the list of "where" and "how" we need to add a "who." How something is done often depends on who does it. That brings in the critical role of institutions. Even if a country has a comparative advantage in a particular area or can correctly anticipate it, the country will not realize its advantage unless the resources are mobilized by appropriate institutions.[17]

According to one view, institutions reflect and respond to changes in the factor endowments of an economy. When the endowments change, the relative factor prices also change and thereby "induce" institutional changes.[18] An alternative view is that institutions reflect market imperfections. The reason institutions exist is that markets often do not perform the functions necessary for efficient production. An institution is a mechanism for bypassing the market.[19]

Information and capital market inadequacies have triggered institutional development in the NIEs. One particularly important institution is the firm. Governments have promoted firms that have the potential to overcome market imperfections. Small countries like Singapore are almost entirely dependent on multinationals. Taiwan (China) has encouraged investment by foreign companies, but has also made a conscious effort to promote domestic firms. Brazil's computer and telecommunication industries have historically been dominated by multinationals. As the Brazilian market has grown and as indigenous capabilities have developed, this has been unacceptable to some groups, leading to a series of policy measures designed to increase local participation. Korea and India have made the strongest efforts to retain domestic control over production. Korea has promoted the growth of private sector conglomerates, while India has relied on public sector firms. The government of each economy has established specialized credit and research institutions to support the operation of these firms. While it is impossible to provide a complete assessment of institutional choice, some examples of successful institutional development are discussed in the following sections.

Evolution of Information Industries in the NIEs

The following discussion covers the experience of some of the NIEs with regard to product sequencing and market choice. It also looks at the capabilities achieved in terms of manufacturing and design efficiency.

Schematic of the Information Industries

Many information products have a low−technology content, while some products embody extremely high research input. Table 15.1 classifies the industry into four sectors in terms of technology and scale levels. The scale of investment is the minimum required for efficient production. By making appropriate technology choices, the investment could be lowered for low−wage countries. However, the difference is unlikely to be large because the scope for substitution between inputs is not high.

The distinction between manufacturing and design in considering the technology levels is important because barriers to entry are *prima facie* lower in the design−intensive sector. The governments of such economies as India, Singapore, Taiwan (China), and the Philippines are hoping to become major players in the market for international design services (particularly software). There is at least some evidence of success in this regard. On the other hand, reputation, credibility, and the ability to keep pace with changing technologies create significant entry barriers. These conflicting forces are examined in the context of emerging mediumsize firms.

Product Choice and Sequencing

The main thrust in the NIEs has been toward manufacturing capability. The approaches followed have, however, been quite different. Electronics production in Taiwan (China) and Korea was initiated in the late 1950s by Japanese and U.S. firms seeking sites for low−cost production of components. The bulk of these components embodied elementary technology. Domestic entrepreneurs were soon attracted to this activity and many small firms sprouted up. Today this is a major sector in the electronics industries of both Korea and Tai−wan (China). The component firms were unable to grow or diversify into other products, but they have served at least two useful purposes. First, they have induced the development of a capital goods industry to produce the machinery required for the assembly of components. Second, as the domestic consumer electronics sector developed, there was a ready and cost−competitive supply of components available. The ready availability of good, low−cost components has given producers in Korea and Taiwan (China) a competitive edge as they move into industrial electronics and office automation products.

The consumer electronics sector in Korea and Taiwan (China) was the main engine of growth until recently. Goldstar and Samsung, the Korean conglomerates, and Tatung and Sampo, the large firms in Taiwan (China), became involved in this sector in the late 1950s and 1960s. The product choice within the consumer sector was determined essentially by demand trends in the United States. The choice was conditioned by the perceived degree of Japanese competition. The Japanese have

Table 15.1
Technological Structure of the Information Industry

Sector	*Examples of products*	*Level of technology* *Design*	*Manufacturing*	*Investment (US$ millions)*
Advanced	Advanced semiconductors, computers, telecommunications equipment	High	High	100 and above
Design intensive	Mini/supermicro computers, software, simple telephone switching equipment	High	Medium/ low	5−25
Medium technology	Color televisions, videocassette recorders, disk drives, microcomputers	Low/ medium	Low/ medium	5−50
Low technology	Black and white televisions, passive components, simple semi−conductor devices	Low	Low	1−20

attempted to continuously differentiate their products and hence generate markets that are relatively price−inelastic. The response from Korea and Tai−wan (China) has been to go into the price−elastic (mass) market left behind by the Japanese. In the 1980s, however, firms in Korea and Taiwan (China) began to try to close the gap vis−à−vis the Japanese. They have sought to differentiate their products and enter markets for more advanced products.

Thus, Korea and Taiwan (China) followed a sequential approach to product selection for about two decades. By the early 1980s, they had a strong component base, trained manpower, and large firms with experience in consumer goods manufacturing and marketing. Korea and, to a lesser extent, Taiwan (China) are trying to use these advantages to increase their competitive strength in high−technology industries. This may be considered a big−push approach in that business and government officials are engaged in promoting products and technologies across the technology spectrum described in Table 15.1.[20]

At the other extreme, India has had no sequencing strategy. For the last two decades, the division of production between components, consumer electronics, industrial electronics (including defense), and communications has remained roughly equal. As a result, one of India's major weaknesses has been a poor component base. Furthermore, there are only weak institutional linkages between the different electronics sectors, making coordination extremely difficult. Brazil has had similar problems. The institutional linkages are probably even weaker in Brazil. The consumer electronics sector has grown in isolation from the computer or "informatics" sector and despite similarity in government policy, the communications and "informatics" sectors do not seem to have formed linkages. Thus, India and Brazil have sought to develop all parts of the electronics complex, but without capturing technological linkages between the different sectors and without fostering institutional linkages.

The important point is that Korea and Taiwan (China) paid more attention to sequencing and also developed better internal linkages. This occurred at least partly because attention to sequencing allowed Korea and Taiwan (China) to establish manufacturing facilities that exploited technological scale economies. As a result, sufficient domestic demand was created for upstream components and subsystems, allowing the upstream industries to produce at economic production scales. In contrast, Brazil and India did not have a sequencing policy; downstream sectors did not develop adequate production scales, which restricted the development of upstream sectors.

Factors Influencing Cost Competitiveness

Cost competitiveness has been influenced by a number of interrelated factors: product sequencing, choice of markets (export and domestic), institutional development, and the degree of competition.

Economies of scale are impeded if there are too many products or too many competitors for the same product. A wide variety of products requires a wide range of components. The Indian electronics industry, for example, has been caught in a trap because its components are produced on a small scale. Component prices have consequently been high, resulting in high prices and low demand for final products. That in turn has reduced the demand for components and limited the growth of the component industry.

In the Brazilian informatics sector, Frischtak has suggested that there has been an excess number of firms:21 ". . .unrestricted entry of national firms in a market of limited economic size may have been responsible for the large unit costs of data processing equipment." According to Frischtak's assessment, Brazilian data processing firms have been unable to achieve technological economies of scale.

A comparison of Korea and Taiwan (China) also suggests that while not the only factor of importance, size has been a valuable aid to growth. In purchasing inputs and even more in international marketing, Korean firms have been able to do much better than their counterparts in Taiwan (China) because they sell large volumes of individual products and they sell several products. For example, for a while, firms in Taiwan (China) had larger exports of PC systems than Korean firms. However, in the past several years, Daewoo and Hyundai have begun marketing large volumes of PCs. The strategy of Taiwan (China) of concentrating on low−margin, low−end export products has hurt Taiwanese information technology vendors, given the crunch in international PC prices, a strong New Taiwan dollar, and rising labor costs and high inflation.22 The Koreans, in contrast, have invested over a $100 million into new computer plants to improve efficiency. To keep pace, Taiwan (China) aggressively cut prices, but the Korean producers have the advantage that they can switch factories from television and VCR production to computers when demand conditions warrant it.23 ,24 Similarly, Korean firms have begun marketing a number of products in the United States under

their own brand names. Firms in Taiwan (China), with minor exceptions, are a long way from that stage.25

In the late 1980s significant wage increases, labor unrest, and soaring currency combined to stall the Korean economy. The *chaebols* (conglomerates) have responded by streamlining management while increasing investment in modem equipment and thus creating the basis for renewed growth.26

The need for economies of scale conflicts with the need to maintain a competitive environment. An attempt can be made to balance these requirements, as for example, in the Brazilian telecommunications equipment industry, where four firms have been allowed to participate. It was believed that four firms would be sufficient to provide a high degree of competition without reducing the potential for achieving scale economies. However, it has been difficult to achieve either a significant amount of competition or cost reductions. Ericsson Telecomunicacões (formerly Ericsson do Brazil), Brazil's largest producer of switching equipment, controls about half the Brazilian switching equipment market, but produces at a cost 25 percent greater than its parent company in Sweden. At least part of the reason, as in India, is the high cost of components.27

The only country that has been able to achieve the "right" balance is Korea. The Korean electronics consumer and industrial electronics industry have been very oligopolistic. Four *chaebols* (Samsung, Hyundai, Goldstar, and Daewoo) dominate the industry. The oligopolistic market structure has been accompanied by severe competition. The firms compete in domestic and export markets through price, quality, and marketing strategies. A number of fierce battles have been fought in the domestic market for VCRs and PCs.28 Each company produces entire product lines rather than specializing in a few models, which makes competition even more intense. This competition fueled Korea's two−decade economic expansion. Thus, while the outlet provided by an export market helps sectoral growth, it is clearly not sufficient, as is suggested by the example of Taiwan (China). Competitive ability in international markets requires large resources for marketing. Only the Korean firms have reached the size necessary to function as major international competitors.

Design−Oriented Sector

For many electronics products, design can be effectively separated from actual production. At the same time, design opportunities are continuously evolving. A large company may develop a product for a mass market, but because of the availability of a wide variety of components and because of the continuous introduction of new components (especially semiconductors), it becomes possible to vary designs to meet the requirements of a more focused customer group (often referred to as a "niche" market).

The NIEs have a possible advantage in this area because of the farsighted policies they have followed with regard to technical education. The entrepreneurs among the engineers in these economies have begun to form medium−size firms. Such firms have sales in the range of $25−$50 million, and they employ a few hundred people. About 25 percent of the employees are engineers, and about 10 percent of sales goes toward R&D. The comparative advantage of these firms is based on design capability rather than on manufacturing strength. These medium−size firms are engaged in a variety of tasks: design of sophisticated computer and telecommunications hardware, systems engineering, and writing applications and systems software.

Some large national firms and several multinational firms have also been attempting to take advantage of the availability of relatively cheap engineers and scientists. In Korea, Samsung Semiconductor and Telecommunications has a few hundred engineers engaged in designing integrated circuits, and Goldstar has links with Olivetti and Hitachi for the development of software. Texas Instruments has set up an integrated circuit design center in Bangalore, India. Citibank has a software development center in Bombay. Ericsson has contracted to provide gateway exchanges in Bombay, Delhi, Madras, and Calcutta, and has been seeking to establish a comprehensive mainland presence. Tata of India is involved with the U.S. firm, Elexi, in a multinational venture located in Singapore. A few multinationals have set up R&D centers in Singapore on a trial basis. IBM has been involved in collaborative software design ventures in Tai−wan (China). Texas Instruments, Hewlett−Packard, Canon, and the Singapore Economic Development Board have made plans to build a DRAM fabrication facility in Singapore.

The utilization of engineering talent in design activities is appropriate for NIEs. For some of them, in fact, that is a better use of resources than hardware production. The technology underlying production of hardware is becoming increasingly capital intensive because of the trend toward automation. This applies not merely to advanced semiconductor devices, but also the computer peripherals, such as floppy disk drives and print−

ers, which require a high degree of precision engineering.

However, there are some problems with the actual realization of this potential comparative advantage in design−oriented activities. The medium−size firms face problems of growth. As noted, they rely on niche markets. Over time, however, a niche market changes character: it either disappears, or it grows into a mass market. If the latter happens, large firms with superior resources are attracted. The ensuing competition is usually very hard on the smaller firms.29 Some survive the competition: Acer of Taiwan (China) has managed to create international production and marketing links, and hopes to capture a 4−5 percent share of the world PC market. Most, however, are unable to compete against firms with larger resources; the Korean computer industry initially consisted largely of relatively small firms, but with the entry of the giants, the smaller firms have been going through a difficult phase.

There is a general presumption that the potential manpower supply in the NIEs is very large, but this may not be correct. The design sector is currently very small (the aggregate annual turnover in India is less than $200 million). If domestic and foreign firms are to enlarge this sector severalfold, the manpower requirements will be very high and it is not obvious that the supply will keep pace.

Domestic firms, particularly the smaller ones, face the problem of becoming obsolete. For example, Indian software exports consist largely of "porting" or upgrading and modifying existing software to match changes in hardware. There are some signs that this market is flat and may even dwindle as hardware designers grow increasingly conscious of maintaining compatibility with existing software. Moreover, automated tools for "porting" software are being developed. Similarly, the increasing use of artificial intelligence techniques in applications software is going to strain the manpower resources of the NIEs.

Strategic Policies

Policy instruments for the development of information industries can broadly be divided into three categories (see Table 15.2). While the categorization of the instruments is necessarily rough, it is striking that Korea has pursued policies in all categories. Brazil and India have relied mainly on infant protection, whereas Taiwan (China) has focused on generating spillovers. The third rationale, "intimidation of foreign competitors," has derived some theoretical justification from the recent work of Brander and Spender (1985), though its efficacy has been questioned by many authors.30

Import Protection

Protection of the domestic market from imports has been a major policy tool for the most NIEs. Market reserve has been practiced by Brazil, Korea, and India. Singapore and Hong Kong are possibly the only two economies that have open economies. Even Taiwan (China) has till recently had high tariff rates on some of its major exports, such as televisions.

Until the late 1980s, Korea used import protection at successive stages to promote domestic production of consumer electronics, computers, and peripheral equipment. Imports of televisions and PCs, two of its major exports, were tightly restricted. Exemptions in the case of computers were allowed if products were destined for use in process control, R&D, or other specialized applications, but these exceptions were granted only in the most extenuating circumstances.31 Similarly, import of almost all important telecommunications equipment required a government license. The Electronic Industries Association of Korea had to

Table 15.2
Strategic Government Intevention

Rationale	*Principal instruments*	*Economy*
Infant protection	Import and foreign investment restrictions	Brazil, India, Korea

Spillovers	1. Foreign investment restrictions	Brazil, India, Korea
	2. Technology policy	Korea, Taiwan (China)
	3. Telecommunication infrastructure	Korea, Taiwan (China)
Intimidation of foreign competitors	1. Subsidies	All
	2. Weak antitrust policies	Korea

certify that the product was not manufactured in Korea.

Only semiconductors have had a low degree of import protection in Korea, possibly because Korean manufacturers felt that they could manage without market protection. For one thing, a market exists within the conglomerates. Further, these large firms have the capacity to sustain losses over significant periods and so are less dependent on subsidies in the form of market protection.

Of all the NIEs, Korea is the only one that has effectively used import protection to gain experience and move down the learning curve. Korean industry has also made effective use of the domestic market during periods when world demand for its products has been weak. In contrast, Brazil and India have had more stringent import protection policies in place, but have been unable to produce internationally competitive products even after long periods of protection. Thus, while market protection can be a useful device for promoting domestic firms, it is clearly not a substitute for making hard choices with regard to products and institutions.

Foreign Investment

Domestic producers are generally unable to compete with the reputations of multinational corporations, access to technology, and economies of scale in production, finance, and marketing. Governments, seeking to foster domestic entrepreneur−ship, are therefore inclined to restrict capital investments by foreign firms. On the other hand, where the gap between domestic and foreign capabilities is wide, the costs of promoting domestic industry can be high.

Brazil and Korea have adopted contrasting methods to achieve national capability in electronics. Brazil has placed special emphasis on the computer and communications sectors, whereas Korea has sought to promote the entire electronics industry. In Brazil, the computer and communications sectors have, for the most part, grown independently of each other, and these two sectors, in turn, have had few links to the consumer electronics industry. In Korea, all electronics sectors (with the exception of passive components) have grown within the folds of the large conglomerates.

In the 1970s and early 1980s, the impetus to develop a Brazilian computer industry came mainly from within the bureaucracy. Many bureaucrats were motivated by their own technological competence and saw an opportunity for Brazil to take advantage of emerging minicomputer and microcomputer technologies.[32] Imports of computers, the technology to make the computers, and foreign investment were all severely restricted.

In the 1980s, Bradesco and Itau, Brazil's largest banks, have made large investments in the informatics industry. The entry of financial capital is changing the thrust of Brazil's strategy. Restraints on the imports of technology are not in the interests of big financial sector users. The banks have negotiated attractive technology transfer agreements.[33] The banks have not only greater negotiating strength, but they also have an interest in maintaining good relations with multinational corporations and have several attempts to promote joint ventures.

Similarly, large industrial users and producers are beginning to form joint ventures with foreign firms. Recent examples are IBM and Gerdau, a steel producer, which will provide data processing services (IBM will hold a 30 percent equity stake); Hewlett−Packard and Edisa, a commercial, industrial, and banking automation concern, will produce mini and super computers.34

In telecommunications as well, the objective was to encourage the participation of domestic entrepreneurs and increase indigenous technological capability. But the strategy was different. In 1977, multinational firms wanting to manufacture in Brazil were required to transfer majority voting rights to Brazilian nationals. (The transfer of voting rights did not imply an equivalent transfer of equity.) At the same time, Telebras, the state−owned telecommunications company, created a research and development center, referred to as CPqD. Telebras also has sought to influence the use of domestic technology through its purchase decisions. Though there are obvious similarities between the telecommunications and informatics policies, the insistence on local technological effort has been weaker in the telecommunications sector. There has been conflict between the Ministry of Science and Technology, which has promoted domestic technology, and the Ministry of Communications, which has viewed excessive control over imports of technologies and products as an impediment to the expansion of the telecommunications network.35

After years of tight restrictions on foreign capital, technologies, and goods, Brazil has recently taken steps to open up its computer market. Several developments suggest that the liberalization of capital, technology, and goods flows in Brazil is here to stay. Restrictions on foreign equity participation in joint ventures have been relaxed. In October 1991, Brazil's long−standing ban on imports was ended, and tariffs for computer gear have been lowered. The ban on production of certain products by foreign companies has been lifted. At the same time, a broader set of international debt−related and macro reforms have induced the return of international capital to Brazil: in 1991 $11.6 billion of foreign capital flowed into the country.36

Korea has also severely restricted investments by foreigners. In Korea, the basis for restriction has been possibly stronger than in Brazil. Those seeking to promote national technology development and the large industrial producers have coalesced in the Korean conglomerates. Korean conglomerates have been aggressive in demanding limitations on foreign investors. This congruence of interest has also meant that Korea has been more successful in developing national capabilities in areas in which it has chosen to focus. In the computer area, for example, the Korean producers started much later than their Brazilian counterparts. However, Korean firms have been able to deploy much larger resources to the design and production of computers than the smaller Brazilian firms.

In the 1980s, Korean firms have begun importing technology through joint−venture agreement, mostly with U.S. firms. U.S. industry views an increased presence in Korea as an important marketing strategy. The Korean conglomerates are in a much stronger bargaining position than most firms in developing countries and can negotiate much better technology transfer deals.

Technology Policy

For the most part, the NIEs have not engaged in basic research, although some of the large Korean firms are beginning to in order to acquire patents—the rights to which they can exchange with foreign companies to access technology, particularly in semiconductors. The main effort has been to generate an educated labor force with the necessary skills to absorb and modify the technology developed abroad. Though general educational policies are critical to training a base of scientists and engineers, specialized institutions have been established to focus on gaining faster access to information technologies. The performance of these institutions has depended on their scale of operation, their degree of commercial orientation, and the strengths and weaknesses of domestic firms. A brief list of the principal institutions in Korea, Taiwan (China), Brazil, India, and Singapore follows.

Korea

The Korean Advanced Institute of Science and Technology (KAIST), the Korean Institute of Electronics Technology (KIET), and the Korea Telecommunications Research Institute (KETRI) were created with a focus on sophisticated science, and the latter two specialized in electronics−related technology. KAIST is responsible for producing the several thousand Ph.D.s and Masters degree holders that the Korean electronics industry needs. KIET and KETRI (which now operate as a single unit called the Electronics and Telecommunications Research Institute (ETRI)), handle product and process development. KIET was set up in 1979 to demonstrate that semiconductors could be produced in Korea. By the early 1980s Korean conglomerates had outgrown KIET's capabilities by licensing foreign technology and by setting up internal R&D departments and "technology−watch" outposts in Silicon Valley.37 KIET proved to be a catalyst, but it could not continue to function as a common semiconductor research center for domestic industry because of strong competition among Korean firms.

ETRI's current activities include development of time division exchange (TDX) technology, which has several applications in telecommunications network building, including the Integrated Services Digital Network. By 1988 ETRI had introduced the TDX−1B with a capacity of 23,000 lines, and in 1989 it started the TDX−10 project to develop a large−scale system of 100,000 lines by the end of 1991. Total R&D costs for TDX through 1991 were projected at $240 million, of which $109 million was provided by the government and the Korea Telecommunications Authority.38

The Korean government has decided to play a larger role in developing semiconductor technology. In the late 1980s, the government designated 500 new high−technology companies for "intensive government support." According to the government's *Year 2000 Report*, R&D spending will increase to 3.0 percent of gross national product (GNP) by the early 1990s and 5.0 percent by 2001. The semiconductor firms have gone through a period of learning on their own. There is now a real possibility that they may be able to compete with the world's leading producers. Firms are attempting to do this partly through technology licensing and alliances. In 1983 the government helped by designating 4MB DRAM technology as a "special research project" and launching the Semiconductor Industry Fostering Plan. A joint research semiconductor institute was created as part of a $240 million program focusing on very large scale integrated circuit (VLSI) chip development, including 4 MB and 16 MB chip technology. The plan also aims at developing design automation technolo−

gies and promoting support industries for semiconductor manufacturing. The leading Korean firms have collaborated on the research. The basic idea of cooperative development of generic technologies is sound and has been used effectively by Japanese concerns, but the degree of cooperation that will actually materialize is not clear. A number of ongoing projects within individual firms have been bundled together to form the project. For the most part, research is continuing in the private laboratories, and the extent or mechanisms of sharing are unclear. The dollar amount of the project is also small in relation to R&D expenditures in the private sector.

Taiwan (China)

The Electronics Research and Service Organization (ERSO) is the focus of the Taiwan (China) government's R&D spending on semiconductor technologies. Facilities have been established at Hshinchu Science City to gain technological synergies in the manner of Silicon Valley and attract high−technology firms from abroad. By 1990 over 100 companies had registered to establish plants, and over 80 had begun operations. In 1988 total output was $1.7 billion. The City's goal is to have about 200 companies in operation by 1996.

ERSO has had a strong commercial focus and operates one of the three silicon foundries in Tai−wan (China).39 ERSO has had much closer ties with domestic industry than KIET in Korea. Because the firms in Taiwan (China) are much smaller than the Korean firms and have a smaller capacity to undertake independent research, there is more cooperation between the government and semiconductor firms in Taiwan (China). Seventy percent of the funding for ERSO's research projects on submicron technology for very large−scale integrated circuits (VLSIs), reduced instruction set computing (RISC) architecture, parallel processing, software technology, and artificial intelligence comes from the government, although this share will decline over time. ERSO has led a $206 million project to create the Taiwan Semiconductor Manufacturing Corporation (TSMC), a manufacturer of foreign−designed integrated circuits.

Brazil

Despite the importance of the computer sector, Brazil has no special institution responsible for research on computer technology. The research has been conducted mainly within firms and, to some extent, in universities. Brazilian firms have had high R&D−to−sales ratios (8−10 percent), and they have also employed a large proportion of engineers. The absence of significant public research is probably explained by the fact that mini and microcomputer technologies were considered widely known.

CPqD, as noted earlier, carries out research on telecommunications and also coordinates research at universities and in industry. The universities do basic research; CPqD and industry share the tasks of prototype and product development. Brazil has followed a big−push policy in telecommunications. This has involved an across−the−board attempt at technological competence. The technology for electromechanical switching has been successful, but transmission systems have been more difficult to master.[40] In the area of digital switching, the Brazilians have developed small exchanges, but they have not yet developed large digital switches.

India

India has a number of electronics research facilities. In addition, domestic electronics firms have devoted a large percentage of their sales revenues to R&D, although to date research efforts have been dispersed and diffused. The small scale of the efforts has entailed low research productivity, and government research institutions have had few links with commercial markets.

The Center for Development of Telematics (CDOT) is an exception to this characterization. CDOT, which is developing small digital exchanges, has had a strong commercial orientation from the start. It has sought to design products with a common set of components and to work with producers to encourage efficient production components. It is still too early to judge whether this approach will be successful since production is just beginning.[41]

Singapore

The Singapore government has focused on developing human resources; for manufacturing technology, Singapore relies on the R&D efforts of multinationals. Singapore's explicit goal is to become a major center of information technology. Singapore set up three computer training and research institutes in 1981—the Institute of Systems Science (ISS), a partnership between IBM and the National University of Singapore; the Japan−Singapore Institute of Software Technology, a joint research project between Singapore and Japan; and the Center for Computer Studies, a partnership between International Computers Limited (ICL) and Ngee Ann Polytechnic (Government of Singapore, 1985). The emphasis is on developing capability in artificial intelligence techniques, gaining expertise in software production under the UNIX operating environment, and increasing software productivity through the use of program generators and other software tools.

Singapore's efforts have paid off. The 1990 *World Competitiveness Report* ranked Singapore first in the world in the number of managers who understand and use information technology, and in the "extent to which IT is effectively used."[42] This accolade reflects not only the serious effort at developing human capital, but also the financing of a world−class telecommunication network, including several innovative specialized value−added networks.

Conclusions

Is the development of a country's electronics industry accelerated by the decision to produce a wide spectrum of information goods and services, or is a narrower focus, based on some indicator of comparative advantage, better? The links between information technologies and the uncertainties inherent in the evolution of these technologies suggest that a broad involvement is desirable. On the other hand, economies of scale and lumpy investments argue for a specific focus. The experience of Korea suggests that both breadth and focus are desirable. Focus is needed in the early stages to develop simple production and organizational skills. Once such skills have been developed, a broader approach to take advantage of technological complementarities and to hedge against uncertainties is desirable.

Of the five economies discussed in this chapter, India has the least developed manufacturing technology and telecommunications infrastructure. Korea and Taiwan (China) have the most advanced manufacturing skills and infrastructure. Brazil stands in between. The governments of all these economies view information industries as the source of significant externalities and have implemented policies to promote them. However, for India, and to some extent Brazil, manufacturing skills in products of low sophistication (passive components, black−and−white televisions) may be a prerequisite for manufacturing more complex products. Even if such skill development is not a prerequisite in a sequential sense, India and Brazil will have to pay significant attention to developing the basic skills. Similarly, telecommunications development must be a high priority.

In Korea and Taiwan (China) where the prerequisites are in place, the difficult question of international competition has to be considered. The high−growth products are also characterized by significant uncertainty, steep learning requirements and short product cycles. To compete internationally, domestic firms need to make large lumpy investments and must be able to sustain losses over periods. In this regard, the Korean conglomerates are better positioned than the smaller firms in Taiwan (China).

Given the potential externalities associated with information industries and the difficulty in cornpeting internationally, governments have used a number of mechanisms to promote domestic firms, including import protection, restriction of foreign investment, promotion of domestic R&D, and development of a telecommunications infrastructure. The role of the government has varied with the needs of the industry. It has typically been stronger when private institutions are less developed. For example, in the 1970s, the Korean government played a strong role in the development of the electronics industry through import and foreign investment controls. It also established momentum by setting up KIET. In the 1980s, those firms have needed less support. As the smaller firms in Tai−wan (China) have attempted to move to sophisticated technologies, the government has been more closely involved in providing research infrastructure and in actual production. It should be noted, however, that recently the Korean government has also taken a renewed interest in the semiconductor industry. Government officials and presumably Korean firms find that they are at a stage at which collaboration could boost the firm's positions. Thus the strategic role of the government changes over time in response to the needs of domestic industry.

Overall, however, the balance has shifted from government stimulus to the development of in−formatics through links with international firms. Throughout, Singapore has relied on international firms as a key catalyst of growth. Brazil has moved toward allowing foreign know−how and capital a greater role in the development of informatics. In southern China, northern Mexico, and Thailand, foreign investors have been central to the growth of information−related industries. However, as the Singapore case highlights, the complementary role of the government in developing human and physical infrastructure will continue to be central.

In the evolving international environment, access to markets and technology will be the key issues. With heightened competition, the developed economies have become more Wary about parting with technology. Japanese firms in particular have followed a policy of minimizing sales of technology; U.S. firms have been more open in this regard, assuming that the collaboration will generate new markets. At the same time, the U.S. government has put pressure on the NIEs (and Japan) to agree to an international intellectual property regime to meet the requirements of the emerging technologies. These developments are at an early stage, and their evolution will have an important bearing on international trade and investment.

Notes

I am grateful to Jane Keneshea and Alexander Hunt for background research, and to Debra Miller for discussions in writing this chapter.

1. Information technology services are extensively discussed in Mody and Dahlman, eds, "Diffusion of Information Technology: Opportunities and Constraints," *World Development,* December 1992.

2. Edwin Mansfield, "R&D and Innovation: Some Empirical Findings" in Zvi Griliches, ed., *R&D, Patents and Productivity* ,The University of Chicago Press, Chicago, 1984.

3. Bela Balassa, *The Newly Industrializing Countries in the World Economy* , New York: Pergamon Press, 1981.

4. Karl Sauvant 1986, *International Transactions in Services: The Politics of Transborder Data Flows,* Westview Press, Boulder and London, 1986, p. 7; Stephen S. Cohen and John Zysman, *Manufacturing Matters: the Myth of the Post−Industrial Economy* , Basic Books, New York, 1987, p. 106; Richard Nelson, *High−Technology Policies: A Five−Nation Comparison* , American Enterprise Institute for Public Policy Research, Washington and London, 1984.

5. Richard Nelson, *op. cit.* , p. 74.

6. Richard Nelson, *op. cit.* , pp. 8−10.

7. Stephen S. Cohen and John Zysman, *op.cit.* , p. 106. These authors use the term "transformative technologies" in a sense very close to Nelson's "leading industries."

8. Stephen S. Cohen and John Zysman 1987, *op. cit.* , pp. 17−24.

9. I am grateful to Francis Colaco for discussion on this subject.

10. Richard Nelson, *op. cit* .

11. Richard Nelson, *op. cit.* , p. 7−8. Has cautioned against the use of formal approaches to tackling uncertain environments. He states that formalism assumes well−defined knowledge of all possibilities; only the realization of these possibilities is uncertain. In contrast, Nelson states that "surprises occur: things happen that no one thought of and that call for the rethinking of the whole program."

12. Paul Krugman, "Introduction: New Thinking About Trade Policy," in Paul Krugmlan, ed., *Strategic Trade Policy and the New International Economics* , MIT Press, Cambridge 1986, p. 7−8.

13. Wafer processing is also more capital and technology intensive than computer production as it currently exists in Korea.

14. *Business Week,* February 3, 1992, p. 44.

15. Richard Barras, "Towards a Theory of Innovation in Services," *Research Policy* 15: 161−73, 1986.

16. Michael Porter, "Changing Patterns of International Competition," *California Management Review* 28(2):9−40, winter 1986.

17. For a similar view on the role of hierarchy and organization in the context of the machine tool industry, see Martin Fransman, "International Competitiveness, Technical Change and the State: The Machine Tool Industry in Taiwan and Japan," *World Development* 14(12):1375−96, 1986.

18. Vernon Ruttan, "Induced Institutional Change," in Hans P. Binswanger, Vernon W. Ruttan, et al., *Induced Innovation: Technology, Institutions and Development,* John Hopkins University Press, Balitmore, 1978.

19. Michael Spence, "The Economics of Internal Organization: An Introduction," *Bell Journal of Economics* 6:163−72, 1975, p. 164, and Ashoka Mody, Growth of Firms Under Uncertainty: Three Essays, Ph.D. dissertation, Boston University, 1987.

20. Though I have stressed the similarities between Korea and Taiwan (China), there are important differences. One example would be that Korea has a greater thrust in the "Advanced" sector and correspondingly a lower emphasis on the "Low Technology" sector.

21. Claudio Frischtak, "Brazil," in Francis W. Rushing and Carole Ganz Brown, eds., *National Policies for Developing High Technology Industries: International Comparison,* Westview Press, Boulder and London, 1986, p. 51.

22. *Datamation* (International Edition) 37 (issue 17), September 1, 1991.

23. . *Business Week*, September 29, 1986, pp. 88−91.

24. Daewoo's Model D PC received a "Best Buy" rating from *Consumer Reports.* The competitive strength of Korean PCs has been described widely in the commercial press; see, for example, *Business Digest of Southern New Jersey*, May 1986, pp. 18 and 21, and the *Wall Street Journal*, November 6,1986, p. 12. Korean producers have also been successful in more sophisticated markets. An example is a highly price competitive color graphics and publishing work station designed and manufactured by Samsung Semiconductor and Telecommunications and distributed by Micro Direct (News Release, July 29, 1986, p. 1).

25. Bo Goransson, "Enhancing National Technological Capability: the Case of Telecommunications in Brazil," Technology and Development Discussion Paper No. 158, Research Policy Institute, Lund, April 1984, p. 7−9. Has noted the empirical importance of economies of scale in purchasing and marketing in the Brazilian telecommunications equipment industry.

26. *Business Week*, December 3,1990, pp. 56−57.

27. See Bo Goransson, *op. cit.* , pp. 19, 30, and 38. Ericsson saw its volume sales increase by 6 percent in 1991, but it also suffered a 2.8 percent decline in net revenues. Contributing to the setback was a government price freeze and a lack of finance (*Gazeta Mercantil* , March 20,1992, p. 31).

28. See *Korea Herald* , December 14,1983, and February 21, 1984.

29. A review of semiconductor start−ups in the United States asks: "But is there life after niches?" *Electronic Business* , August 15,1987.

30. See contributions to Paul Krugman *op. cit.*

31. Based on Ashoka Mody, "Korea's Computer Strategy," Harvard Business School Case Study, 1985, p. 5.

32. There is a large amount of literature on the Brazilian computer industry. Peter Evans, "Varieties of Nationalism: the Politics of the Brazilian Computer Industry," in Antonio Botelho and Peter Smith, eds., *The Computer Question in Brazil: High Technology in a Developing Society* , Center for International Studies, MIT, 1985 and *State, Capital and the Transformation of Dependence: The Brazilian Computer Case* , Center for Comparative Study of Developments, Brown University, 1985. Immanuel Adler,

"Brazil's Domestic Computer Strategy," *International Organization* 40(3):673−707,1986. Ravi Ramamurthi, "Brazil's Computer Strategy," Harvard Business School Case Study, 1985. My description is based primarily on the papers by Evans.

33. Digital Equipment Corporation has licensed its VAX 11/750 and Data General has licensed its MV4000 and MV8000.

34. . *Business Latin America,* October 27, 1986, pp. 330−31.

35. *New York Times,* September 16, 1985, p. D8.

36. . *Business Week,* May 11, 1992, p. 54.

37. Daewoo purchased Zymos, a U.S. firm, to gain access to semiconductor technology.

38. Cae−One Kim, Young Kon Kim, and Chang−Bun Yoon, "Korean Telecommunications Development: Achievements and Cautionary Lessons," *World Development,* December 1992, forthcoming, pp. 18−19.

39. Other foundries are being built by the sector.

40. Based on a discussion with Björn Wellenius.

41. Bharat Telecom has set up a plant in Ludhiana to produce electronic private branch exchanges using CDOT technology *(Economic and Political Weekly,* September 5−12, 197, p. 1528).

42. Seng Hong Wong, "Exploiting Information Technology: A Case Study of Singapore," *World Development,* December 1992, forthcoming, p. 2.

PART IV—
CONCLUSION

16—
Electronics Development Strategy:
The Role of Government

Carl J. Dahlman

This chapter provides an overview of the role of government in developing the electronics sector in four developed and seven developing economies and summarizes some lessons from their experiences. Government has been actively involved in the development of the electronics sector in all the economies examined, except that of Hong Kong. This involvement has taken different forms with different degrees of success, which gives rise to a number of questions.

How successful have the different governments been in accomplishing their objectives? To answer this, government objectives must be identified clearly and sufficient information assembled to judge whether those objectives have been met. This is complicated because of the multiplicity of objectives, some of which may be in conflict. For example, it is not possible to have a technologically independent industry that is also internationally competitive. The high costs of developing technology and the speed of technical change mean that no economy can be a technological leader in all areas. Although some economies—those of India and the People's Republic of China (PRC), until recently—were autarkically oriented, even they have recognized that to be internationally competitive, they must make use of foreign technology.

How effective have different government strategies been in increasing the competitive performance of the electronics industry? Though this question is narrow, measuring performance is difficult—because performance can vary over time as firms learn better production. Moreover, technology and best practice change over time, making performance not an absolute concept but a relative one.

A third question concerns the cost at which competitiveness is achieved. This is difficult to judge because it is necessary to examine not only the direct costs of using public funds for research and investment, but also the opportunity cost of those funds and—to the extent that protection exists—the additional costs to consumers of more costly, protected products. This area also involves intertemporal issues and the social rate of time discount. Moreover, cost assessment is complicated further because performance is a "moving target," so to speak. Learning may occur for the protected product, but better products based on different technologies may be developed, and the learning that occurred in producing the first product may not be transferable to the production of the second.

This chapter outlines the main rationales for government attention to developing the electronics industry, possible roles of government, and some common instruments and strategies. The chapter goes on to characterize the strategies and instruments used in each economy and provides comparative data on the size, nature, and importance of the sector. The final section draws some general conclusions and policy implications for developing economies.

Framework

Many different rationales have been invoked by governments for their involvement in developing the electronics sector. Because of its rapid growth and increasing importance as an input into many other areas of economic activity, electronics is considered a key sector of industry. This is because electronics has the potential for directing economic

progress across a broad front, much as the development of steam power and electricity did many decades ago. Electronics also is considered to be of strategic importance, in a narrow sense, as a critical input in advanced defense, and in a broader sense as a critical base for national economic strength and international competitiveness. Thus, the rationales for government support of the sector are particularly related to the perception of electronics as strategic rather than as just a leading industry.[1]

Various governments have emphasized the military over the commercial as a rationale for the strategic importance of the electronics sector. The United States traditionally has put the most emphasis on the military rationale; the United Kingdom, France, Brazil, China, and India have followed suit. Japan, the Republic of Korea, Tai−wan (China), and Singapore have emphasized developing the electronics sector for industrial competitiveness. However, while these objectives have had some influence on how the electronics sector has been promoted in various economies, most instruments for promoting electronics development are common to both the military and commercial approaches.

The Role of Government

Three different dimensions of the role of government in promoting a sector should be made explicit. The *first* involves government programs and actions that directly target the promotion of a selected industry—in this case, the electronics industry, or even products. This targeting can be accomplished through a wide range of instruments.

The *second* dimension is more generic: functional targeting of activities such as research and development, investment, and technical education. Although these activities are not sector specific, they can have an important indirect, promotional effect to the extent that some industrial subsectors have a greater need for subsidized inputs. The electronics industry, for example, with its heavy research and intensity in science and engineering, indirectly receives preferential promotion through an economy's general incentives for industrial research and development (R&D) or for technical higher education. The more capital−intensive segments of the electronics sector also indirectly receive preferential promotion from industrial incentives or allowances, such as accelerated depreciation and other tax write−offs.

The *third* dimension is the quality of macroeconomic management and the degree to which appropriate policies and institutions permit flexible adjustment in capital and labor markets to changing conditions. This role of government is often overlooked in discussions of industrial policy, but mounting evidence shows that it can be critical to structural change and competitiveness.[2] This is particularly relevant to the electronics industry because of the rapid pace of technical change, as well as the global nature of its market, and its high degree of international competition. In this last regard, it should be noted that international competitiveness and growth are increasingly sensitive to technological capability and the ability to compete on delivery as opposed to unit cost of production as such (see OECD 1990b and Fagerberg 1988). This means that basic physical infrastructure, such as telecommunications, ports, and airports—where government plays a big role—are increasingly important elements of an economy's competitiveness.

Main Instruments and Strategies

The main governmental instruments for promoting development of the electronics sector include the following:

Direct participation in the sector through state enterprises

Trade protection, export promotion, and export performance requirements

Publicly−financed research and development carried out in public R&D laboratories, universities, and firms

Fiscal and financial incentives for industrial R&D in the sector, for establishment of firms in the sector, and for purchasing the sector's products

Government procurement guarantees for specific products

Regulation of direct foreign investment in the sector

Instruments of industrial organization that can be either antitrust−oriented, to prevent concentration and encourage licensing, or pro−concentration, to promote concentration and large holdings

Development of technical human resources

These instruments can be used in varying degrees depending on the extent of government commitment to the sector and its sector development strategy. Following are five key elements of government strategy:

Degree of specific targeting in the sector

The mix between private and public, and between local and foreign participation in the sector

Narrowness or breadth of the targeted sector

Sequencing, if any, in moving from one segment of the electronics subsector to another

The focus on domestic versus global markets—including the sequencing of entry into each

Country Experiences

The eight instruments of government action used across selected economies are provided in Table 16.1. The economies' reliance on each of the five main strategic approaches—targeting, ownership control, broad support, sequencing, and market−oriented moves—are highlighted in Table 16.2.

Several clarifications are in order before delving into the economy experiences. First, over time the role of government and the relative importance of different instruments have differed within as well as across economies. Second, the electronics sector involves several segments, and the strategies and instruments used in each have often been different. The tables merely summarize the role of government in a general way. The following sections on each of the economies add nuances.

The United States—The State Obsessed With Defense but Without a Plan for the Private Sector

The U.S. government has targeted heavy financing toward R&D in electronics. The initial development of the electronics sector in the United States was led by the Department of Defense (DOD). Government contract research and procurement related to defense have exerted perhaps the most important direct U.S. government influence on the development of the sector, particularly semiconductors.3

Trade protection has not been very important in the U.S. electronics industry. In the 1970s the United States negotiated import quotas on televisions from Japan, Taiwan (China), and Korea. In 1986 it negotiated a semiconductor agreement with Japan. No specific fiscal and financial incentives for R&D, special investment incentives, or guaranteed government purchase of electronics products, except for defense orders, exist.

Although other economies' industrial policy has been used to promote mergers and consolidations to increase international competitiveness of their electronics industry, U.S policy has focused on antitrust enforcement to prevent the formation of domestic monopolies and to facilitate the licensing of technology.4 A prime example is the consent decree of 1956 that confined AT&T to the telephone business and forced it to license its semiconductor technology to third parties. This decision prevailed until 1981 when AT&T itself was broken up and thereafter permitted to engage in the computer business outside of telecommunications.

Perhaps the most important role of the U.S. government has been its heavy investment in higher and technical education since World War I, which put the United States far ahead in science and technology until the late 1970s and early 1980s when other economies, most notably that of Japan, began

Table 16.1
The Role of Government by Main Instruments

Economy	*Direct participation*	*Trade protection*	*Public R&D*	*Fiscal/ financial incentive*	*Government procurement*	*Direct foreign investment control*	*Industrial organization*	*Special human resource strategies*
Brazil	Medium	High	High	High	High	High a	Neutral	Low
China	High	High	High	High	High	High	Pro	Low
France	High	Medium	High	High	High	Medium	Pro	Medium
Hong Kong	Low	Low	Low	Low	Low	Low	Neutral	Low
India	High	High	High	High	High	High	Anti	Low
Japan	Low	High b	Medium	High	High	High b	Pro	High
Korea	Low	High c	High b	High	High	High	Pro	High
Singapore	Medium	Low	Medium	Medium	Low	Low	Neutral	High
Taiwan (China)	Medium	High	High	High	High	Medium	Anti	High
United Kingdom	Medium	Low	High	Medium	High	Low	Pro	Low
United States	Low	Low	High	Low	High	Low	Anti	Low

a . Very restrictive in minicomputers, and some in telecommunications, not in other sectors.

b . Early period.

c . Except for semiconductors.

Table 16.2
Government Strategies

Econmy	*Targeting*	*Control*	*Breadth*	*Sequencing*	*Market orientation*
Brazil	High foreign a	State/private unintegrated	Semi−broad	Unsequenced	Domestic
China	High some foreign	State/ unintegrated	Semi−broad	Unsequenced	Domestic
France	High	State/private	Broad	Sequenced	Mostly domestic
Hong Kong	Low	Foreign/private	Narrow	Unplanned	International
India	High	State/private b	Semi−broad	Unsequenced	Domestic
Japan	High c	Private	Broad	Sequenced	International

Korea	Medium	Private/ integrated	Broad	Sequenced	International
Singapore	Medium	Foreign/state d	Narrow	Sequenced	International
Taiwan (China)	High	State/private integrated	Broad	Sequenced	International
United Kingdom	Medium	State/private	Broad international	Unplanned	Neutral, *de facto*
United States	Low e	Private	Broad international	Unplanned	Neutral, *de facto*

a . State strong in telecommunications, minicomputers; foreign strong in large computers, consumer electronics.

b . Very little foreign.

c . But higher in the past than now.

d . Very little local private.

e . Except for emphasis on defense.

to catch up.5 However, the heavy investment in technical education did not specifically target electronics.

With the exception of Hong Kong, and excluding the military sector, the United States has had the least directly interventionist policy for developing the electronics sector. Maintaining this strategy has been possible due to the early spinoff of electronics from the military, the huge size of the electronics subsector, the high science and technology base with abundant technical personnel, the dynamic private sector, and flexible capital and labor markets. The large domestic market and the flexibility of capital and labor markets have been essential for the start−up of many innovative firms. Many such firms are spinoffs formed by personnel who worked for larger established firms or research facilities and who were able to raise capital through the active U.S. venture capital market.6

To some extent the uncoordinated approach in the United States has been a reflection of an underlying philosophy that industrial planning is not the role of government. However, in the last few years concern in the United States has been growing that the government must devise a more activist policy if the United States is to stay ahead of its strong competitors, Japan and the European Community (EC). This new approach—for more government coordination—is reflected in changes in antitrust policy and the creation of various research consortia, as well as in the recent debate about government support for a program to develop high−definition television (HDTV).

The National Cooperative Research Act of 1984 relaxed enforcement of antitrust prohibitions for interfirm collaboration in precommercial research. This facilitated the establishment of the Microelectronics Computer Corporation (MCC), SEMATECH, and other research consortia. MCC is a consortium of 20 U.S. computer and semiconductor manufacturing firms to explore technologies that will be used in the next generation of computers.7 However, there have been problems in getting its member firms to cooperate. MCC has also been criticized for potentially reducing the number of technological alternatives pursued by independent firms, traditionally one of the powerful forces for innovation and growth of the industry.8

MCC is a private consortium, but the government has taken a direct role in SEMATECH, a research consortium of 14 U.S. producers of microelectronic components.9 DOD is contributing $600 million in matching funds to this research consortium over six years (Mowery and Steinmuller 1990). DOD believes that U.S. suppliers of defense components cannot survive without a strong presence in commercial markets and that they need research subsidies to support the development of commercial technology. The consortium is closed to non−U.S. firms, which is an embarrassment when U.S. firms want to join similarly restricted consortia in Europe. Unlike the Japanese cooperative research efforts, which tend to focus on the development of generic precommercial technologies, SEMATECH's objective is to develop advanced commercial production technology for standard integrated chips (ICs), such as dynamic random access memories (DRAMs). However, many doubt how effectively the competing U.S. firms will cooperate to develop commercial technology that is to be shared by all the members of the consortium.[10]

Proponents of a greater government role in supporting HDTV appear to have been set back because of the lack of support from the Bush administration. However, pressures for a greater government role in supporting the electronics industry continue to be strong, and new initiatives are likely to be passed. These initiatives stem from the rapid fall in preeminence of the United States in the world electronics industry in the last few years. Flamm (1990), for example, has shown that the U.S. share of world production of the consumer, industrial, and components segments of electronics fell from 13.5 percent, 55.3 percent, and 45.9 percent respectively in 1985, to 7.8 percent, 41.7 percent, and 33.5 percent in 1988.

The United States, however, still has the largest electronics production and market (Table 16.3). Its electronics sector consists of almost 19,000 firms and employs more than 2.6 million people, making it the largest manufacturing sector in the United States.[11] Its leading segments are electronic data processing equipment—especially large computers—and communications and military electronics. Medical and industrial electronics, as well as communications and the military, account for a greater share of U.S. production than in other economies (Table 16.4). Conversely, the United States has the smallest share of production in consumer electronics; other economies, particularly those of Japan and the East Asian newly industrialized economies (NIEs), have overtaken the United States in the consumer electronics segment. The United States has the lowest ratio of exports to production among the developed economies, since the United States is the world's largest market and since it has begun to lose competitiveness in many less sophisticated electronics products.

Table 16.3
Aggregate Electronics Data, 1989

	US$ billions					*Percent*		
Economy	*Imports*	*Exports*	*Production*	*Market*	*GDP*	*Production/ GDP*	*Market*	*Exports production*
Brazil	1.3	0.8	10.2	10.7	319.2	3.20	3.3	7.8
China a	1.7	0.1	5.4	7.2	417.8	1.86	1.7	1.9
France	18.0	13.1	25.7	30.6	955.8	2.69	3.2	51.0
Hong Kong	12.4	15.3	7.7	4.8	52.5	14.75	9.1	198.7
India	0.9	0.4	4.1	4.6	235.2	1.74	2.0	10.0
Japanl	3.9	73.8	185.2	125.3	2,818.5	6.57	4.4	39.8
Korea	6.4	15.1	22.5	13.8	211.9	10.62	6.5	67.1
Singapore	9.7	15.7	12.5	6.5	28.4	44.01	22.9	125.6
Taiwan (China)	7.3	13.1	13.9	8.1	148.2	9.38	5.5	94.2
United Kingdom	26.0	19.5	26.0	32.5	717.9	3.62	4.5	75.0

United States	65.1	48.5	198.5	215.1	5,156.4	3.85	4.22	4.4

Note: Electronics includes equipment for electronic data processing, offices, control and instrumentation, medical and industrial uses, communications and the military, and telecommunications plus consumer electronics and components. See Table 16.4 for a breakdown by economy and type of product.

a . Data for China is for 1983.

Source: Import, export, production and market data for all economies except China are from *Yearbook of World Electronics Data*, volumes I and IL 1991, Oxford, Elsevier Advanced Technology, 1991; for China, data on electronics are from World Bank, *China Electronics Sector Report*, Washington, D.C., 1989; GDP data are from World Bank, *World Development Report 1991*, Washington, D.C., 1991, except for Taiwan (China), which are taken from Council for Economic Planning and Development, *Taiwan Statistical Data Book, 1991* .

Table 16.4
Percentage Breakdown of Electronics Production by Economy and Use, 1989

Economy	*Electronic data processing*	*Office equipment*	*Control and instrumentation*	*Medical and industrial*	*Communications and military*	*Tele−communications*	*Consumer electronics*	*C*
Brazil	29.7	92.98	4.56	2.14	6.59	14.14	21.68	18
China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.
France	25.25	1.64	8.52	2.18	25.13	15.34	5.09	1
Hong Kong	20.69	4.61	1.39	1.49	7.25	5.52	30.68	28
India	11.46	2.03	6.04	1.88	13.59	10.56	36.84	1
Japan	29.48	2.96	3.71	2.68	4.64	7.41	17.29	3
Korea	14.12	1.23	0.67	0.64	2.24	8.42	28.74	4
Singapore	42.93	2.48	1.49	0.38	1.65	2.09	16.04	3
Taiwan (China)	29.41	2.91	0.60	1.34	4.25	9.09	17.75	3
United Kingdom	28.89	2.69	15.31	3.79	16.52	11.18	5.93	1
United States	24.83	2.85	12.31	4.31	24.12	7.59	3.17	2

n.a. Not available.

Source: Yearbook of World Electronics Data, volumes I and II, Oxford, Elsevier Advanced Technology, 1991.

Japan—The State as Private Sector Coach and Coordinator

In Japan the role of government in developing the electronics sector is quite different from the role of government in the United States, the United Kingdom, or France. The Japanese government has constantly worked to identify and eliminate bottlenecks impeding continued progress—and to provide a national vision of future possibilities. This has been done within a framework of active consultation with the private sector, with actions directed at supporting and strengthening the private sector rather than at supplanting it. Another special characteristic has been the government's many carefully−coordinated support policies: trade and foreign investment protection, support for research and development through conditional loans and consigned payments, and encouragement of appropriate market structures.

Tariffs, quotas, and other trade barriers were used extensively in the 1960s and early 1970s to protect the development of computers and semiconductors.12 These restrictions were used to bargain for access to foreign technology. Starting in 1972, quotas and restrictions on foreign investment and technology transfer were gradually relaxed. By 1976 trade and investment in computers were completely liberalized. Today computer tariffs in Japan are lower than European tariffs, but slightly higher than in the United States.13

In the early 1950s and until 1960, research on computers was carried out mainly in government laboratories,14 since private, corporate R&D labs scarcely existed. In 1960, when IBM was allowed to set up production in the local market, the government launched a five−year plan to produce Japanese computers. In support of the plan, the government raised import barriers and required access to foreign technology as the admission price for foreign firms to enter the local market.15 From then on, the Ministry of Trade and Industry (MITI) played a vigilant role supporting the development of local industry in response to advances made by IBM.16

Government support for research and development was great relative to private industry's own R&D efforts in the early 1960s. In the early 1970s, MITI shifted its funding toward joint research associations. In 1974, when MITI's funding reached a peak of 25 percent of all funds for computer research, nearly half of total computer research in Japan was carried out in joint research associations. Beginning in 1978, private R&D took off dramatically, and although the level of MITI funding remained more or less constant, by 1984 it was only 4 percent of the total. However, Nippon Telegraph and Telephone (NTT) has become a more important research funder than MITI, accounting for about one−fifth of the total in 1984, most of that with private firms.17

Through MITI, the government also has influenced market structure to improve Japanese competitiveness. For example, when IBM launched its 370 System in the early 1970s, it knocked computer companies such as General Electric, RCA, and Xerox—which had been the foreign partners for some of the Japanese computer companies—out of the field. MITI's response was to consolidate six independent computer producers into three groups and increase funding for research and product development. Collusion among Japanese

electronics firms has not appeared to be a problem. In fact, fierce competition among firms has tended to be the problem, which often has undermined the collaborative experiments promoted by MITI, including the above−mentioned rationalization. However, MITI has been successful in playing the coordinating role, especially in fostering cooperative precompetitive research through its financial incentives to joint research associations.

Japan also has used tax and loan policies as an explicit instrument of industrial policy to promote the computer industry. Tax benefits favor R&D and exports from all producers in general, but special tax benefits accrue to computer producers and users alike; these benefits are fine−tuned every two to five years. Subsidized credit through the Japan Development Bank has also been important to the computer industry. One of the largest programs of subsidized credit was channeled through the Japan Electronic Computer Company (JECC), set up with help from MITI in 1961 to buy locally−produced computers and lease them−to users in competition with IBM's leasing program. At its peak in the late 1960s, JECC accounted for as much as 80 percent to 90 percent of Japanese shipments (excluding deliveries of foreign computers).18 MITI also helped establish the Japan Information Processing Development Center (JIPDEC) in 1967 to market software and provide training. Its activities eventually led to the so−called Fifth−Generation Computer Project.

An important Japanese program was the very large−scale integrated circuit (VLSI) program of the late 1970s. This actually consisted of two programs: one designed by NTT to develop and procure ICs for telecommunications, the other designed by MITI to bring Japanese companies to state−of−the art generic technology for computer ICs. The salient features of the MITI project were its organization around several corporate R&D labs and its joint funding by the companies and MITI.19 A more recent program is the fifth−generation project. This is a 10−year endeavor financed in part from consigned research grants from MITI to develop a new computer architecture for symbolic computing and artificial intelligence. This program provoked widespread reaction in the United States and Europe.20

Japan is second only to the United States in electronics production, but is the world's largest exporter (Table 16.3). The electronics sector consists of about 35,000 companies employing 1.9 million workers. Although components account for the largest share of Japanese production, consumer electronics account for the largest share of its electronics exports. Japan dominates world markets in video cassette recorders (VCRs) and other advanced consumer electronic products. In its production structure, unlike in the other developed economies, the largest subsector is components rather than electronic data processing, which is second. Moreover, its consumer electronics subsector, which is third, is much larger than in other developed economies. Conversely, reflecting Japan's limited thrust into defense applications, the communications and military subsector is the smallest among the developed economies and even among the quasi−continental developing economies, such as in Brazil, China, and India. In the 1980s many Japanese companies relocated their more labor−intensive operations to developing economies and automated their operations in Japan. Japanese companies have also set up more than 100 factories in Europe, in part to overcome possible barriers to imports as a result of EC92.

In summary, the Japanese strategy has been to consolidate its production, first in the simpler areas such as consumer electronics, which it did in the 1950s (radios and black and white televisions) and 1960s (color televisions), then to move into computers and semiconductors. Initially the domestic market received protection, but gradually opened up as the industry matured. However, Japan has the lowest ratio of imports of electronics products to size of domestic market (Table 16.3). In the case of computers and semiconductors, the government focused more on positive measures for investing in R&D and joint research than on protection alone. It also emphasized higher education in science and engineering; since the late 1970s Japan has been graduating more electronics engineers than the United States, although it has only half the population of the United States.

The United Kingdom—The Schizophrenic State Now Focusing on the Private Sector

The development of the electronics sector in the United Kingdom has been closely linked with defense. However—unlike the United States—the United Kingdom has experimented with various forms of direct intervention in developing electronics. Government R&D expenditures motivated by military needs have been heavily concentrated in electronics and telecommunications—almost one−third during the 1970s. Unlike in the United States, electronics and communications firms in the United Kingdom have spent less of their own money on R&D than the government has contributed.21

In the United Kingdom trade policy has not been used much to protect local industry. How−

ever, government procurement has been used extensively to develop the national electronics industry, and the government has taken direct equity positions in some electronics companies. For example, in 1968 the government formed the computer firm ICL by promoting a series of mergers, supported by government financing and R&D aid, and by promising public sector purchases of computers.22 Similarly, the government invested heavily in the firm INMOS in 1978 in an attempt to create a world−class semiconductor manufacturer. In addition, the government has developed various programs to stimulate the use of electronics technology in other sectors. Through the Microprocessor Applications Project (MAP) it funds up to 25 percent of the costs of product development in order for manufacturers to incorporate microprocessors into their products. Through the Microelectronics Industry Support Program (MISP), also started in 1978, it gives financial and other support to firms manufacturing ICs.

U.K. government funding for many of the state−invested firms, as well as for many technology application programs, has not been consistent, and the government has begun relinquishing its investments in some companies. This posture partly reflects an inconclusive internal debate as to whether having manufacturing capability in semiconductors is necessary as opposed to focusing only on applications. Because of stop−and−go policies, combined with a liberal DFI strategy, foreign firms have captured the major share of the U.K. market, except in the defense sector.23 The failure of U.K. support policies for the electronics industry is best illustrated by the fact that INMOS is an affiliate today of SGS Thompson, ICL belongs now to Fujitsu, and Plessey was acquired by GEC Siemens.

The electronics sector in the United Kingdom consists of about 7,500 companies employing around 370,000 workers. These comprise a small number of indigenous firms, such as GEC, Racal, Plessey, Ferranti, and STC, and most of the large world multinationals in electronics, such as IBM and Philips (these two account for over one quarter of all the United Kingdom's products). As in the United States, the electronics data processing subsector is the largest, followed by communications and military applications. However, the segment in which the United Kingdom has the largest share is electronics control and instrumentation. The slow growth of electronics in the United Kingdom has been the result of the government's stop−and−go support for it and the slow rate of economic growth in the United Kingdom. The slow growth of the U.K. market has been overcome to some extent by the high−export orientation of U.K. electronics production. The United Kingdom has the highest export−to−production ratio among the four developed economies (Table 16.3). Much of these exports are made by affiliates of foreign companies to the EC market.

France—The State as Chief Architect and Planner

France has the most centralized and coordinated policymaking among advanced Western nations. As in the United States, defense concerns have played a great role. The government role increased in 1964 when the United States refused to sell France large computers for the development of fusion weapons. At the same time, General Electric purchased Machines Bull, a faltering French computer manufacturer. This convinced the French government of the need to develop its own, independent computer industry. The result was a concerted thrust in computers, known as *Le Plan Calcul.* The government merged two existing manufacturers to create CII a public corporation that was built up as a "national champion" to compete internationally with IBM. The government poured massive funds into CII, provided export subsidies, protected it against competitors in the local market, and guaranteed domestic procurement.24 However, CII was not successful and in 1975, when the failure of *Le Plan Calcul* was evident, CII merged with Honeywell Bull.25

The military's need for semiconductors led to the 1977 *Le Plan des Composants,* designed by the ministries of defense, industry, the postal service, and the telecommunication company. Learning from the failure of *Le Plan Calcul*, this plan supported not one "national champion" but five firms—including three joint ventures with U.S. firms for the infusion of advanced technology. This plan appears to have been more successful in raising the level of French technology. The R&D portion of this plan supported work on very large−scale integrated chips (VLSIs) as well as microprocessor applications.

The French government also launched a major plan to advance development and applications of telecommunications, and forced the sale of two foreign−owned telecommunications subsidiaries to the national, government−owned, Thompson group. Roughly half the French electronics sector is state owned. France's Eleventh Five−Year Plan (1981−85) targeted electronics for special support, including research, nationalization of relevant firms, and massive investments in electronics by both public and private companies.26

France currently has the largest telecommunications market in Europe. The telecommunications military subsector underwent a major reorganization with the absorption by CGE of ITT's worldwide telecommunications business in 1986, followed by the takeover of Matra Ericsson by GGCT and the privatization of CGE in May 1987. More recently, France has been trying to strengthen its position in consumer electronics. In 1987 Thompson acquired U.S. General Electric and RCA consumer electronics product divisions.

France has the smallest electronics production and market size among the four developed economies considered here, as well as the lowest share of electronics production as a share of gross domestic product (GDP). More than 750 electronics companies—including about 100 foreign firms—employ about 220,000 workers. The French electronics industry has been pushing for a tightening of European content of Japanese consumer electronics manufacturing plants established in Europe, as well as for a "Buy European Act." Consistent with France's preoccupation with defense, the military segment has a large share in French electronics manufacture—the share for military uses being the largest among the 11 economies reviewed in this chapter (Table 16.4). The telecommunications share in France is also the largest among the 11 economies, partly reflecting the recent government push to develop telecommunications. The French electronics industry also has a high export−to−production ratio, thanks to the rationalized production of foreign MNCs, such as IBM, HP, TI, Philips, Siemens, and Canon. Government direct investment in the industry has always been a major priority in France, although the government in power since 1986 has started the privatization of several state companies, such as Thompson, Bull, and Matra.

Before turning to the strategy of developing economies, a few comments on more general efforts taking place in Europe are in order.27 The perceived failure of many of the individual national programs in Europe to catch up with the United States and Japan has led to a proliferation of programs at the EC level. This began at the end of 1981 with the four−year Microelectronics Program (Regulation 3744/81) to stimulate R&D for production and testing equipment for manufacturing very large integrated circuits. This modest program did not succeed in closing the technology gap, but it did lay the groundwork for similar, more ambitious programs (Howell et al. 1988).

The European Strategic Program for Research and Development in Information Technologies (ESPRIT) was launched in 1984. ESPRIT is a 10−year program funded at $2.75 billion and intended to close the EC's technological gap in information technology with the United States and Japan. The program is designed to stimulate precompetitive R&D activities in information technology by supporting collaborative projects among governments, industries, and research centers in EC member states.28 By 1987 over 500 organizations had participated, and about half the projects funded are said to have had some positive results. In April 1988 a second phase was approved with funding of about $1.87 billion. This phase is supposed to be more market driven and also to focus more on basic research (Palmintera 1989).

Furthermore, in reaction to heightened European concerns of being left behind when the United States announced its plans to spend massive amounts for research on the Strategic Defense Initiative, the Europeans, led by French President Mitterand, launched an initiative to increase European research. This led to the establishment of the European Research Cooperation Agency (EUREKA) in 1985 to promote cooperation on technology research and development in the 19 economies representing the EC, EFTA, and Turkey.29 By 1986, 72 projects budgeted at more than $3 billion over a 10−year period had been adopted. Most of the projects are concentrated in microelectronics (Howell et al. 1988.)30

In addition, in 1987 the EC launched a program parallel to ESPRIT—the Research and Development Program in Advanced Communications Technology (RACE). RACE focuses on R&D that will lead to a standardized broad−band communications network in Europe. Its priority areas are electronic components, optical equipment and integrated optoelectronics, specialized communication software, and flat panel displays for terminals. The total research budget is expected to be about $2.3 billion, half funded by the EC, half by industry.

Various other EC−sponsored cooperative research programs also focus on electronics. The Basic Research in Industrial Technologies for Europe (BRITE) program funds research and development in industrial manufacturing technologies and advanced materials applications. As with most of the EC projects, BRITE requires participation from at least two member countries and funds half the total project costs. The rest has to be funded by industrial participants. Almost 400 projects were being funded in 1989, and BRITE's budget for that year was about $585 million (Palmintera 1989).

Although the results of these programs are not yet apparent, and their total budgets are still a small fraction of the total budgets allocated to R&D in electronics in Europe, they do indicate the great

emphasis that the European governments are giving to technology in general and electronics in particular. Furthermore, there are strong concerns that to the extent that the Europeans are not able to close the technology gap with the United States and Japan through subsidies to R&D in the context of EC92, they may be more likely to resort to trade−related restraints to protect the local electronics industry. Indeed, the EC has already stipulated that the diffusion step in wafer fabrication has to be done within the EC for the product to be considered European. This local content requirement will make it more difficult for non−EC economies to export semiconductors to the EC.31

Brazil—The State as Nationalist Leader With a Differentiated Approach32

The Brazilian government has played a strong role in developing all the key segments of electronics, although with a different approach toward each. A common element in the development of three segments—telecommunications, computers, and consumer electronics—is that trade policy has been used extensively to protect the local market and thus to foster the development of local industry. The objectives and the instruments used have varied across subsectors.

In telecommunications, the objective has been to develop a strong domestic industry. The main instruments the government has used have been public procurement policy and direct involvement in R&D. In 1967 a government holding company (Telebras) was created for the national and state telephone service companies. In the mid−1970s the government established a policy for local production and procurement of telecommunications components and equipment. The goals were to establish a more solid domestic industrial base and to save foreign exchange. This program had two parts. One was to increase the requirements, first, for greater local content in the supply of equipment to the Telebras system and, subsequently, to aim for greater preference toward Brazilian−con−trolled companies. The second part of the program was to increase R&D in order to prepare Brazilian companies to use new technology and produce new telecommunications products.33

In 1976 Telebras established the *Centro de Pesquisas e Desenvolvimento* (CPqD) as its formal research unit,34 and by the end of 1987 CPqD had developed 75 different products, many in cooperation with universities and industry. At least 25 of these new products were being manufactured as a result of an active technology transfer program to local industry.35

A 1981 law stated that suppliers to Telebras of electronic switching equipment had to be Brazilian−controlled companies. The law also reserved the digital switching market to the family of digital exchange systems called *Tropico,* which were being developed by CPqD. As a result, foreign telecommunications equipment suppliers producing in Brazil (Ericson, NEC, Siemens) had to restructure to become majority Brazilian−owned joint ventures; wholly−owned Brazilian companies were strengthened as well. Delays in development of the *Tropico* program allowed the joint venture companies to bring out their own digital designs for medium−sized (4,000−10,000 lines) and large (more than 10,000 lines) exchanges based on foreign digital technology. The market for smaller exchanges (fewer than 4,000 lines) continued to be reserved for CPqD's *Tropico* R system. Furthermore, half the market for up to 20,000 lines has been guaranteed for the *Tropico* RA exchange technology, which was scheduled to be available from CPqD by the end of 1989.

The Brazilian government, through Telebras' procurement policy, has been successful in developing the local telecommunications industry. By 1987, over 100 firms supplied diverse telephone and telex exchanges, and domestic value−added ranged from 60 percent to 70 percent for telephone exchanges to nearly 100 percent for telephones, VHF radios, and multiplex pulse code modulation (PCM). However, except for the most standardized products, Brazilian prices are higher than international prices. The gap has widened since the beginning of the 1980s because of the lack of sufficient competition, fragmentation of the market (partly induced by firm−licensing policies), restrictions on foreign technology, and the high cost of most components.36

Brazil's technological achievements have been impressive, but at what cost and for what benefits? Taking the *Tropico* program as an example again, Frischtak (1989) estimates that the development of the *Tropico* R exchanges cost between $105 and $250 per line and that the price of domestic manufactured exchanges is $400−$550 per line (including a 3 percent royalty paid to CPqD). That compares unfavorably with international digital switching equipment prices of $120−$180 per line. Part of the reason for the high local manufacturing costs is Telebras' practice of certifying individual producers and assuring them a minimum demand, which has reduced the benefits of larger−scale economies. On the benefits side, it may be argued that the *Tropico* R is a more appropriate product because it is more adapted to Brazilian conditions. It can also be argued that the high development cost is an

investment in developing technological capability and that future, larger versions are going to be cheaper and faster to develop. On the cost side, however, Frischtak points out that because of a delay in the delivery of the *Tropico* R technology— after the market had been reserved for it—Telebras continued contracting large volumes of electromechanical exchangesbetween 1980 and 1985 rather than using foreign digital technology. This meant a higher cost to the Brazilian economy.37

In computers, the objective has been to develop a strong nationally−owned industry from supermicros down to home computers, peripherals, and subassemblies. The government has reserved that segment of the domestic market for Brazilian companies. The policy to develop a national computer industry dates from the mid−1970s when Brazil's military government decided that the economy should develop its own computer manufacturing capability. The local industry would thus substitute for computer−related imports, which were one of the primary drains on foreign exchange in the economy (along with imported oil). However, the government recognized that it would not be feasible to develop a national industry to produce large mainframes and has left that segment to foreign−owned multinationals (IBM and Unisys) already producing in Brazil.

In 1977, Capre, the government agency for computer imports, selected five Brazilian firms to support in computer production. Two firms based their products on local technology, and three used foreign technology. In 1979 Capre was replaced by the *Secretaria Especial da Informatica* (SEI), a special secretariat for informatics with links to the National Security Council, to plan the development of the national informatics industry. SEI has been active in identifying areas for national production, calling for bids by Brazilian companies and awarding production licenses to Brazilian firms, including licenses for many component product areas. In 1983 the government set up a public research center for informatics, *Centro Tecnologico da Informatica* (CTI), to develop local informatics technology.) However, unlike CPqD, it has not developed strong links with the industrial sector. The government also passed special fiscal incentives for R&D that apply only to firms in the informatics sector.

By 1985 the value of sales by Brazilian computer companies surpassed sales by domestically−based foreign companies.38 However, prices for Brazilian computers are significantly higher than international prices. Furthermore, Brazilian computers are not likely to become internationally price competitive with the current industrial structure. The industry is too fragmented, with many national manufacturers producing at an uneconomic scale. In addition, Brazil jumped into computer production without first developing the components;

the components industry remains weak and inefficient.

In consumer electronics, the objective has been to use the industry as part of the Amazon regional development program, without concern for local versus foreign ownership of firms.39 In return for firms locating in remote Manaus, far from the main markets in southeastern Brazil, and submitting to some local−content requirements, the government provides special incentives. These include quotas for imports, elimination of import duties on capital goods and electronics parts, elimination of income tax for 10 years, and provision of special financial incentives.

Although the policy was successful in inducing the consumer electronics industry to relocate and expand in Manaus (Philco, Philips, and National are there), virtually no link exists between the consumer segment and the rest of the electronics industry in Brazil. In addition, due to the industry's strong inward orientation in response to the protected market, production scales do not match international standards. In color televisions, for example, at least 10 producers have fragmented the market. As a result of such fragmentation, Brazilian prices are also higher than international prices in most other consumer electronics products.

In the structure of the production of information technology (IT) hardware, EDP is the largest sub−sector (30 percent), followed by consumer electronics (22 percent) and components (18 percent). The relatively large share of EDP can be attributed to the special emphasis that has been given to that subsector for market reserve. Compared with that of the other developing economies, the share of components in total production is low, except for India, which suggests that this critical subsector is underdeveloped in Brazil. This is a particularly serious weakness, because Brazil restricts imports. Overall, the electronics sector consists of about 2,800 companies employing about 260,000 workers.

How successful has Brazil's strategy been? An absolute judgment is hard to make since Brazil has acquired much experience in the production of IT hardware, which may be relevant to its future development. However, some indicators, aside from the high Brazilian prices, suggest that its strategy has had many shortcomings. First, and reflective of its high prices, Brazil has the lowest ratio of exports to production among all the economies covered in Table 16.3, except that of China.40 Because of its tight market reserve policy, Brazil has a lower ratio of imports to domestic electronics market

than even India (see Table 16.3). Second, despite the strong protection and stimulus for the development of the sector, the ratio of production to GDP is lower than any of the East Asian NIEs. Third, and perhaps most indicative of the shortcomings of its past policy, the ratio of apparent consumption to GDP is a little more than half that of the two developed economies and only one−seventh to half that of East Asian NIEs.41

China—The State as Lonely Actor Looking for Foreign Partners42

In a centrally−planned economy, the state, by definition, plays a critical role in the development of any sector. The Chinese government has given the electronics industry priority because of its importance for defense and industrial modernization. Starting from a small base—the few prewar plants that existed were severely damaged during World War II—in 1949 the government began to rehabilitate the industry with assistance from the U.S.S.R. Since 1949 the electronics industry has grown at about twice the rate of the rest of the industrial sector.

One of the major changes in China in the past decade—its opening to the rest of the world—has had an important impact on policies, structure, and access to foreign technology in electronics. Since 1979, the government's focus has shifted from military electronics to consumer electronics and computers, as well as to the establishment of an integrated circuit industry. Military electronics is estimated to have fallen from a 60−80 percent share of the sector 10 years ago to about 10 percent now.

Several government ministries are engaged in electronics R&D, production, and application—the main one being the Ministry of Electronics and Industry (MEI). Until recently, MEI administered electronics activities in most of the factories as well as at the major research institutes, specialized training centers, and universities. However, in 1986 MEI turned over most of the daily management of the formerly centrally−controlled factories to local electronics bureaus. MEI now concentrates on strategies for the long−term development of the sector. In 1988 MEI merged with the Ministry of Machine Building to form the Ministry of Machine Building and Electronics (MMEI).

Trade policy has been one of the main instruments for developing the sector. Imports of competing products have been regulated or permitted only under high tariffs. Effective rates of protection for some of the key products range from 50 percent to 170 percent, but noncompeting electronics imports (components and products) pay much lower duties, on average.

Until 1979 China relied mostly on old Soviet technology and its own technology to develop the electronics sector, but the open−door policy in the past decade has attracted DFI into the electronics sector. Direct foreign investment has been channeled into labor−intensive electronics components and consumer products, which are being abandoned by more advanced economies as they move into higher value and more complex products. DFI is also being used to fill gaps in several critical areas of electronics where a new injection of technology is necessary—television tubes, integrated circuits and, most recently, video tape recorders and compact discs. Having started from zero, by 1986 joint ventures accounted for almost 5 percent of total electronics output in China.

Although China has also spent over $2 billion on imports of technology and equipment to modernize its electronics industry, estimates are that its electronics sector is still about 10 years behind the international frontier in most areas (except some military electronics applications, formerly the area of its strength in electronics). Because of the fear of being left behind, China has liberalized access to foreign equipment and know−how substantially. In addition, measures have been taken to encourage firms to carry out more R&D and to make independent R&D centers report directly to enterprises rather than to government ministries.

All segments of electronics in China are characterized by a high fragmentation of production capacity, which means that in most cases they are far below minimum efficient scales of production. The largest producer of personal computers, for example, made only 20,000 units in 1987, compared with scales of over 200,000 units for most international producers maintaining or increasing their market shares. In addition, enterprises lack the capacity for specialization, in part because they diversified into unrelated electronic activities after the demand for military electronics declined. There are problems of coordination of production of plants controlled by different provincial and municipal governments. Thus, supply networks also are poorly developed, and many manufacturers have invested heavily in in−house production of most of their required components and subassemblies, at inefficient scales. As a result of these inefficiencies, poor management, the need to carry large inventories because of the unreliability of supplies, and high tariffs, and taxes, the prices of Chinese electronic products tend to be significantly higher than international prices.

To promote greater product specialization and economies of scale and scope in production, marketing, distribution, and R&D, the Chinese government has been encouraging the formation of large group companies. More than 26 groups have been formed; they already account for over half of electronics production. Intergroup rivalry is expected to provide an important element of domestic competition. It is also hoped that the large verticallyintegrated groups will become important exporters. In addition, to promote efficient scale, the government plans to require industrial licensing by MMEI for large projects, to prevent excessive entry and fragmentation in five critical areas of electronics (switching systems, computers, integrated circuits, video tape recorders, color television tubes). Such projects will be screened for technical and managerial capability, and only licensed firms will be permitted to produce.

The current government strategy is to concentrate on the low and medium end of consumer electronics as the major engine of growth for the electronics industry. This strategy is expected to help the rest of the electronics sector by providing expertise in high−volume manufacturing and assembly; experience with product design, development, engineering, and assembly; and know−how on sourcing components and parts—through developing an effective network of suppliers of electronic materials, components, and manufacturing and testing equipment. The consumer electronics segment, especially color televisions, is also expected to be China's major base for promoting exports of electronics products. Color television technology is relatively mature, China has a sufficiently large domestic market for economies of scale, and its low labor costs provide some advantage. However, the infrastructure for active components, printed circuit boards, and electronics−grade production equipment and materials is weak, and prices are high. Moreover, the capital goods industry has been slow to respond. China would do well to learn from the experience of Korea and Taiwan (China) that developing the supporting industries as part of an effective product sequencing strategy is important.

In spite of being the largest of the developing economies in population and in apparent consumption of electronics, China's electronics production is considerably smaller than that of the four East Asian NIEs. The latter have followed export−oriented strategies because of their smaller size. China has the lowest export−to−production ratio of all the economies reviewed.

India—The State as Main Actor and Regulator43

India's electronics industry, established by the state in the 1960s, has developed in a heavily protected environment, in which the state has been the main actor and regulator. Public sector enterprises still account for about 40 percent of the electronics sector's output. Indian Telephone Industries (ITI) and Hindustan Cables Limited (HCL) dominate telecommunications; only since 1984 have private firms been allowed to produce. Several large public sector enterprises also dominate the industrial electronics subsector. Two public sector enterprises dominate components as well, producing all small and medium−sized ICs. Large−scale ICs are still imported. The rest of the electronics sector is fragmented, since an explicit government policy reserves part of the sector for small−scale producers. More than 24 product areas, some of which require scale for efficiency, were reserved for small industry until recently.

Industrial licensing requirements by the government have severely regulated entry and exit of firms and restrained the growth of the most efficient producers. Larger firms were prevented from expanding because they were dominant or foreign owned. By encouraging geographic dispersion of the industry among the country's many states, the government prevented the geographic concentration necessary for developing a strong supportive infrastructure.

The Indian electronics sector is domestically oriented, with only 10 percent of production exported. It imports about half the required materials and components. High tariffs and bans on competing imports have led to high levels of effective protection, which has prevented competitive pressure and discouraged exports. In 1989 the sector consisted of about 2,600 firms employing approximately over 230,000 workers. The industry is mostly local with few foreign firms because of tight regulations for foreign firms until the recent liberalization.

Because of the Indian government's stringent policy of technological self−sufficiency, strong restrictions on DFI and on technology transfer have been the norm.44 Such constraints, combined with a heavy public enterprise presence, as well as the policy of reserving a large part of the components subsector to small−scale enterprises, have resulted in an inefficient sector with high costs. In some product lines, production scales are substantially smaller than minimum efficient scales by 20 to 100 times. Process technologies are generally 8 to 10 years behind, and product technologies generally 5 to 6 years behind. Indirect taxes and high customs duties on imports amount to 20 percent to 30 percent of sales prices. In 1986, for 10 major products, Indian factory prices were 20 percent to 170 percent higher than world prices, and many products were of inferior quality. One of the few areas in which Indian firms could be competitive by world standards, if they could get inputs at

world prices, is consumer electronics based on relatively simple and mature technologies. Another area for potential international competitiveness includes products that require skilled labor or computer software, both of which are low cost in India.

In the 1980s the government targeted electronics as a source of productivity improvement for the industrial and service sectors. As a result, and especially since 1985, electronics has been singled out for a series of liberalizing policy reforms: gradual liberalization of the restrictions on entry and exit; more flexibility to adjust both output mix and capacity in those sectors still subject to licensing; virtual elimination of the policy of reserving some products for small−scale industry; and access to imported capital goods assured through an open general license category.

Telecommunications, formerly the exclusive preserve of the public sector, was opened in 1984 to the private and joint sector for the manufacture of telephone handsets and PABXs; this broadened in 1988 to include rural exchange and transmission equipment (for majority state−owned firms). Improved access to foreign technology and relaxation of restrictions on firms with more than 40 percent foreign ownership have taken place, parallel with domestic deregulation. Finally, quantitative restrictions have been greatly reduced for components, and the import duty structure has been rationalized, with raw materials generally at 35 percent, processed parts at 50 percent, components and peripherals at 80 percent, and final products from 90 percent to 150 percent.

Though belated, these policy changes are having some positive effects on the competitiveness of Indian electronics. Since 1985, ex factory prices have fallen by as much as 60 percent for some products, such as color televisions and microcomputers. Exports of electronics products (excluding those produced in duty−free zones), which were stagnant in 1984, have more than tripled since then, growing from 2.7 percent of production to 3.9 percent in 1987 and 10 percent in 1989. However, the policy changes have not gone far enough.45 India still has a long way to go to become internationally competitive across a wide spectrum of electronics products.46

Partly as a result of its policies, India has the smallest electronics production among the economies reviewed. With China, it has the smallest ratio of electronics production to GDP and low import and export ratios. In the structure of the sector, it has the highest share of production in the consumer electronics subsector.47 However, it has the lowest ratio in electronic data processing. On the other hand, it has a broadly diversified sector with the highest shares in control instrumentation and communications and military use among the developing economies reviewed. This is reflective of the strategy of going for great breadth and little sequencing. It also reflects the strong role of the military in the sector.

Korea—The State as Creator of Private Conglomerates to Battle Abroad

A large part of Korea's success in developing its electronics sector can be attributed to its four largest conglomerates—Samsung, Goldstar, Daewoo, and Hyundai.48 The government fostered the development of these conglomerates as a way to reduce its transaction costs in dealing with the private sector and with the desire to create large firms capable of defending themselves in foreign markets.49 These four have done well in the fast−moving electronics industry because their deep financial pockets, cross−subsidization activities, internal technical labor markets, and economies of scale allow them to compensate for market failures characteristic of high−technology products. Such market failures include requirements for lumpy capital investments, difficult access to product and process technology, and general uncertainty.50

Samsung and Lucky Goldstar entered the electronics market in the 1950s, producing consumer electronics and progressing from radios to black and white and then color televisions based on imported technology. Eventually they entered the computer and semiconductor markets, and Daewoo followed later; all three compete across a wide range of electronics products. Hyundai was a latecomer and did not pass through the consumer electronics stage, but rather entered the computerand semiconductor fields directly in the mid−1980s. All have integrated facilities for producing up to 1 MB DRAMs.51 Samsung and Goldstar also already have facilities for the production of 4 MB DRAMs. In 1988, Samsung (with sales of almost $1 billion) ranked eighteenth among the world semiconductor companies, and is expected to become one of the world's top 10 soon.

The Korean government's main resource for strengthening the large conglomerates was subsidized credit directed to such firms through the national banking system.52 It should be clarified, however, that the government did not promote these conglomerates exclusively for exports and for the development of the electronics industry. It promoted them mainly for the development of heavy

industry. These conglomerates branched out into many subsectors, eventually spawning the electronics industry.

Although consumer electronics started as local assembly operations by Japanese and U.S. subsidiaries, the Korean government placed tariffs and quantitative restrictions on imports of consumer electronics products and computers, and restricted foreign investment, all to promote production by national companies. The only unprotected sector was semiconductors, which the conglomerates undertook to develop on their own, not at the government's urging.

Government procurement was important in the development of the computer and telecommunications subsectors in Korea.53 The government also set up a large public research and technical training infrastructure to foster development of researchers: the Korea Advanced Institute of Science and Technology for advanced technical degrees and research, as well as two more specialized research institutes dedicated to the electronics sector. The first was the Korea Institute of Electronics and Technology (KIET). The other research center was the Korea Electronics and Telecommunications Research Institute (KETRI, now called Electronics and Telecommunications Research Institute [ETRI]).

KIET was set up in 1979 to help bring industry to a state−of−the−art level in semiconductor technology and to stimulate cooperative research in the private sector. However, once the private sector realized the possibility of producing semiconductors locally, it moved forward with its own production lines based on technology licensing and foreign expertise. In 1985 KIET's facilities were sold to one of the large Korean conglomerates because they were becoming obsolete as research facilities. Although KIET did not fulfill its objective of fostering cooperative research among private firms, it played a catalytic role in demonstrating that it was possible to produce semiconductors in Korea. It also trained researchers and engineers who then migrated to the private sector.

ETRI originally focused on telecommunications, but subsequently absorbed the functions of KIET. It has been important in developing advanced telecommunications protocols and transmission devices. ETRI also coordinated joint research on the development of the I million DRAM and 4 million DRAM by Korean firms. However, the big conglomerates have their own advanced electronics research facilities, and government research centers have had to switch their role to more generic precompetitive research.

In Korea about 1,200 firms employ 410,000 workers in the manufacture of electronics products. More than half the firms produce parts and components. Almost 85 percent are locally funded. The rest have some foreign capital. The main foreign firms are IBM, Motorola, National Semiconductors, Philips, and Fujitsu.

Korea's electronics production was lower than that of Taiwan (China) through the early 1980s, but it grew more rapidly. In the early 1980s, it overtook Taiwan (China) and by 1989 it was almost twice as large (Table 16.3). In addition, Korean industry has moved into electronics products, such as VCRs and more complex computers and components, of higher value than those produced in Taiwan (China).54 Mody (1989a) attributes this to the advantages of scale and scope of the large Korean conglomerates. Therefore, an important part of the success in electronics seems to be based on the government's early decision to foster the development of large conglomerates to battle in international markets. The largest segment is components, whose 44 percent share is the highest for any of the economies in the sample (Table 16.4). The second highest share is consumer electronics. This reflects the sequencing strategy of starting from mere assembly of consumer electronics products and then deepening by producing the components. Korea, however, is still heavily dependent on imported parts and components—mostly from Japan.

Taiwan (China)—The State as Incubator and Supporter

The electronics industry in Taiwan (China) started in the 1960s when the government changed its industrial policies from an import−substituting orientation to export promotion—basically exportoriented assembly for foreign companies. The government set up various incentives for exportoriented industry, including export processing zones (EPZs). The low−cost labor and the export facilities of Taiwan (China) attracted many foreign electronics firms. The export industry grew quickly, with much spill−over to the local economy of direct and indirect diffusion of foreign production technologies, management and marketing techniques, subcontracting with local firms, and training. The industry that developed was based primarily on consumer electronics, starting with radios and progressing through black−and−white televisions in the 1950s and 1960s to color televisions in the 1970s, and finally to monitors and minicomputers in the 1980s.55 It was also strong in

watches, toys, and telephones based on imported ICs.

In the mid−1970s, however, the government began to emphasize further development of the electronics industry due to its increasing importance domestically and with the objective of achieving international competitiveness. At the end of 1981, electronics and machinery were given priority status as strategic industries. The Ministry of Economic Affairs (MOEA) initially selected 151 strategic products, of which 64 were related to electronics.56 By 1987 there were 199 strategic products, of which 91 were electronics−related.57 Incentives for manufacturing strategic products included low−interest finance, assistance in technical and operational management, exemption or reduction of tariffs on machinery imports, and income tax reductions.58 ,59

More generally, the government has also provided a nurturing and supportive environment, through the establishment of the Hsinchu Sciencebased Industrial Park, to encourage foreign high−technology companies to locate in Taiwan (China) and to nurture the development of local companies. The industrial park was established in 1980 and by 1987 had over 70 firms, mostly in electronics.60 The park provides a supportive environment, which besides the basic physical and administrative infrastructure, includes special tax incentives, low financing (even equity participation), manpower and management training, and great technology support infrastructure. The latter includes the Industrial Technology Research Institute (ITRI) (discussed in this chapter), as well as two of the top technical universities in Taiwan (China).

Different strategies have been used to develop different parts of the industry. One of the clearest contrasts is the strategy for the VCR industry and semiconductor industry. For example, strong import controls were used to develop local production of VCRs. In 1982, 1,533 items from Japan were banned as part of the plan of Taiwan (China) to reverse its large trade imbalance with Japan. One of these products was VCRs. Since Japan was virtually the sole world producer at that point, the ban on Japanese imports amounted to a ban on virtually all VCR imports. However, this ban benefitted a local company that had started research and development to produce VCRs domestically and had previously entered into technology licensing agreements with Toshiba and JVC of Japan for local production; the company was able to start up production within a few months of the ban's imposition. Other local companies began production over the next five years, one under a licensing agreement with Sharp and one as a joint venture with a Japanese company.

However, the orientation of VCR production continues to be toward the domestic market. Firms lack the economies of scale to be efficient low−cost producers. In addition, about 60 percent of the VCR components are imported, and although import duties on VCRs were reduced to 35 percent by 1986, those on components remained at 50 percent. Thus, in 1986 local VCR prices were still above world prices. Korean VCRs were making inroads in the domestic market of Taiwan (China), and exports from Taiwan (China) were small in comparison to Korean VCR exports.61 ,62

In contrast to VCRs, the semiconductor and computer industries have been promoted mostly by developing a strong technological base while keeping an open import policy. One of the main instruments has been the Electronics Support Service Organization (ERSO), established in 1974 as a specialized research center within the ITRI, which is the premier public research institution for industry in Taiwan (China). ERSO's major function is to help the government carry out research in electronics for both the public and the private sector. When ERSO began, the electronics industry of Taiwan (China) relied completely on imported ICs.63

The first major responsibility of ERSO was to acquire and develop the IC technology for production in Taiwan (China) and to transfer it to the private sector, as part of the government's Electronics Industry Research and Development Plan. To do that, ERSO first studied and visited 30 leading semiconductor manufacturers in the United States. It then licensed technology from RCA and, with the assistance of RCA engineers, set up a production facility within the research center. Once the research center was successful in designing and manufacturing ICs, the government used the new expertise to help establish the United Microelectronics Company (UMC), a joint venture with the private sector and the first firm successfully to produce ICs locally. ERSO participated heavily in the design and technology transfer to the UMC, including the transfer of many engineers from ERSO.64

ERSO also has been influential in developing the electronics industry further in Taiwan (China). As part of the government's Very Large−Scale Integration Plan (1983−88), ERSO established the Center for Common Design Service to diffuse IC design technology to industries and to help them design the specific−function ICs. Many IC design companies in Taiwan (China) have been set up by former ERSO circuit design managers and staff. In 1987

ERSO also helped set up the Taiwan Semiconductor Manufacturing Company (TSMC), a joint venture between ERSO, local private industrialists, and Philips of the Netherlands.65 TSMC is a silicon foundry that produces IC masks from design specifications provided by local and foreign clients. In addition, ERSO has helped local firms import, assimilate, improve and develop technology and products, and set up or expand plants; it has also trained many engineers and researchers working in the private sector.66

On the software side, to promote the development and use of computer technology, the government in 1979 established the Institute for the Information Industry (III). Its objectives include introducing and developing software technology, assisting government agencies and public enterprises in computerization, and training and educating professionals in the information area. It has developed a comprehensive 10−year program to achieve this.

In the education area the government has stressed the engineering fields, especially electronics engineering. According to the III, by July 1987 there were 114,628 graduates from the electronics and information science fields and another 57,942 studying in the same fields in colleges and universities. In addition, the government established two special programs to help provide in−service training in this area. The first is through public training institutes for entry−level and middle−level manpower. The second is a five−year promotional plan for the information industry to train at least 1,000 government employees annually in computer−related courses. Furthermore, the government has established a comprehensive certification program for workers in the informatics area. It tests the ability of workers and certifies them at different levels, which provides the flexibility needed to complement the rather rigid formal educational system.67

Electronics in Taiwan (China) consists of more than 3,300 firms employing at least 300,000 workers. Overall, Taiwan (China) has the second largest electronics sector among developing economies, having recently been surpassed by Korea. Moreover, the production of Taiwan (China) is both more import intensive and more export oriented than the Korean electronics sector (see Table 16.3). In the structure of the sector, components account for the highest share, followed by electronic data processing and consumer electronics. The unit value of exports in consumer electronics from Taiwan (China), however, tends to be lower than that of Korea's exports.68 Companies from Taiwan (China) tend to specialize in niche markets, which capitalize on their ability to absorb foreign technology, and to invest and produce quickly for fast returns.

Singapore—The State With an Integrated Approach to IT

Singapore, the most IT−intensive economy of the group, began IT development in the mid−1960s, after the separation from Malaysia left it with relatively abundant, low−cost, and disciplined labor that it used to attract direct foreign investment. This initial strategy worked well and led to a rapid increase in wages and national income. Singapore furthered this process by developing the skills of its labor force and by building up a world−class physical infrastructure—in particular, the port, the airport, and the telecommunications system.

Perceiving the increased importance of IT and knowledge− and service−based industries in the early 1980s, the government began to pursue a policy of substituting capital for labor through greater automation, mechanization, and computerization; through investment promotion programs aimed at attracting higher−value and more skill−intensive foreign investment; and through improvement of skills of the labor force.69 In addition, in 1980 the government created a national committee on computerization to spearhead a national strategic thrust based on IT, and in 1981 a National Computer Board (NCB) to help computerize the ministries, train software professionals, and encourage expansion of local computer software and services industries. However, in 1985, partly as a result of pushing too fast for a rapid increase in wages as part of the strategy of moving toward high−value activities, the economy went into recession. This led to some quick downward adjustment in wages to restore international competitiveness. It also led to the development of a new national IT strategy for Singapore that sought to integrate government−supported programs to exploit the synergy between the hardware, software, and telecommunications subsectors to improve productivity and competitiveness and to develop a stronger export orientation.70

The new national plan had several strategic thrusts (Wong 1990). First, it focused on IT applications for the civil service. Second, it encouraged participation in the hardware and software industry by multinationals as well as local companies. Third, it emphasized education and training in skills relevant to IT, drawing on the global technological leaders to develop an extensive software engineering capability in Singapore.71

Although the government has not used trade policy to develop the local electronics industry, it has set up several key public enterprises in the electronics and informatics areas. These are linked with the defense establishment and with software development in more traditional government areas, such as managing the airport and port traffic and the newly built subway system. In addition, through the EDB, the government has been instrumental in attracting high−technology direct foreign investment to the IT industry.

The plan has worked well to date. Singapore has sustained one of the highest per capita growth rates in the world. The share of IT hardware output in GDP is 23 percent, the highest in the world. Its production structure is unique in that it has the highest share of electronic data processing because of the production of equipment by the foreign multinationals in Singapore. The second largest sub−sector is components, with consumer electronics a distant third. Singapore also has the highest apparent consumption of IT hardware relative to the GDP of any economy in the world (Table 16.1). Singapore also has the highest intensity of use of IT products per capita among the developing economies covered. In addition, Singapore has one of the highest densities of fiber optic networks in the world. In fact, the 1989 *World Competitiveness Report* rated Singapore's telecommunications infrastructure as first in the world, ahead of runners−up the United States and Canada (Wong 1990). In 1989, Singapore was the first country to implement ISDN on a nationwide scale. In all, Singapore is becoming not only an important producer, but also perhaps one of the most avid users of IT in the world, and it has effectively used IT to enhance its international competitiveness.

Hong Kong—The Laissez−Faire State in Trouble

Consistent with its general strategy of *laissez faire* , the government of Hong Kong has not had a direct role in the development of its electronics industry. Electronics started up in the late 1950s and early 1960s with transistor radio assembly plants. These were well suited to Hong Kong, requiring little technical know−how, cheap labor, and relatively little capital. Radio assembly grew quickly. In 1962 it expanded into electronic components for radios because Japan imposed an embargo on the export of its components to Hong Kong, due to Hong Kong's success. The ban was soon lifted as Japanese suppliers realized that Hong Kong could manage without Japanese supplies. By 1968 the components sector accounted for 52 percent of electronics output. In addition, in the late 1960s production diversified into television and computer components and assembly of television sets. By 1970 electronics accounted for 10 percent of total domestic exports and 9 percent of manufacturing employment. Over 70 percent of the electronics exports went to the United States—with many U.S. firms using Hong Kong as a cheap offshore production site for sales to the U.S. market. Hong Kong's electronics industry also got a boost from Japan, the world's largest supplier, when the latter shifted to higher−priced radios and was faced with restricting its sales to the United States.72

In the 1970s and early 1980s, Hong Kong's electronics industry diversified further into many consumer products and components, including high−fidelity components for sound systems, cassette recorders, electronic watches and clocks, electronic toys and games, and wired and cordless telephones. More recently, it has also diversified into computers and computer peripherals (modems, disk drives, floppy disks, printers, computer memories, and add−on cards), PABX, cellular phones, facsimile machines, and computer−aided design and testing equipment. It also produces multilayer printed circuit boards, liquid crystal displays, quartz crystals, and semiconductor devices, including integrated circuit wafers. In addition, it also has a number of software houses serving its sophisticated market.

In 1989, the electronics industry was the economy's second largest exporter after the clothing industry, and accounted for 22 percent of domestic exports. It consisted of more than 3,700 firms employing 150,000 workers. The majority of firms are small, locally−owned component producers or assembly plants, but there is still a heavy foreign presence of large multinationals, including Digital, Epson, Motorola, National, NEC, Philips, and Sanyo.

The structure of production is heavily weighted to consumer electronics, particularly the lower end—radios, toys, watches, and simpler televisions and computers (Table 16.4). Among the 11 economies being reviewed, Hong Kong has the highest share of production in office equipment, mostly calculators. Hong Kong also is both the most import dependent and export oriented. Imports are 161 percent of electronics production, while exports are 198 percent of production. The electronics industry in Hong Kong is therefore mostly an assembly industry based on imported components that are used in low−end electronics exports.

Until recently, the technology to assemble and manufacture fast−changing consumer products was considered relatively unsophisticated. Companies

spent only a small share of sales on R&D and aimed for short−term returns based on quick production for niche markets. More sophisticated products are produced mainly by assembling advanced components imported from Japan. However, because of the threat of the rapid growth of application−specific components, Hong Kong has seen the need to break away from assembly−intensive work into the design and manufacture of more specialized products. Thus, recently the government has become more interested in assisting the industry and has started to focus on improved education and training of electronics engineers and promotion of direct foreign investment to obtain the more advanced technology needed to remain competitive. These efforts also include setting up a technology development center and a science park to support the development of high−technology industry.

Conclusions and Policy Implications

Clearly, the questions raised at the beginning of this review cannot be answered entirely satisfactorily, even with more data than are currently available. What follows presents some preliminary judgments on the relative success of different strategies and the probable reasons for those successes. First, a distinction must be made between "leader" and "follower" strategies. A leader strategy is based on being the technological innovator and requires a strong scientific and technological base. A follower strategy is based on being fast at bringing the new products to market. Unless impeded by high barriers to entry, being a follower is easier because there are clear guideposts. Until recently, the United States was clearly the leader in electronics technology. The economies of Europe and Japan, along with the developing economies, have been followers. Governments have had scope to identify gaps or problem areas and to plan how to approach such problems. The material below focuses on the followers, particularly the developing economies, although reference will necessarily be made to Japan because of its relatively recent transition in status from a developing country to a developed country and because of its clear success in electronics.

The most successful performers in developing internationally competitive industries have been Japan, Korea, and Taiwan (China). Although they have tended to rely on the private sector, the state has played an important role as well—as coach, father, and nurturer, respectively. Possibly the complexity of the strategies required to be successful in such a dynamic sector makes it necessary to rely on agile private sector players. Hong Kong has also been successful, although its success has been limited primarily to simple consumer electronics goods and computers. The prospects of its moving rapidly up to more complex products are unlikely because of its shallow technological base for electronics. This shallowness relates partly to the lack of investment in technological infrastructure, which in turn is related to the *laissez−faire* attitude of its government. Yet Hong Kong's strategy has some merits, as attested to by the rapid growth in electronics output and the increase in quality. Hong Kong's electronics sector thrives on flexible adaptation to new market niches in the simple products area, based in large part on its excellent integration into international supply and export networks.

Singapore, too, has succeeded in building a large, rapidly−growing, export−oriented electronics industry. Singapore's strategy is highly reliant on foreign capital and know−how, which implies lack of local control. But, as in the case of Hong Kong, the issue of foreign control is just another wrinkle in these city−states' extreme dependence on international markets for their very survival. Furthermore, the rapid growth and expansion of the electronics sector has led to much employment and an increase in living standards in Singapore.

The least successful in international competitiveness have been India and China. They are the poorest in per capita income, although not in the absolute size of their technical human resources. Part of the reason for their relatively poor performance in electronics appears to have been their excessively autarkic approach until recently, along with the heavy state presence and control of the electronics sectors.

Brazil's experience lies between that of China and India, on the one hand, and the East Asian NIEs, on the other, though probably closer to the former. Brazil set out to develop a nationally owned and controlled computer industry and has clearly been successful. A more difficult issue is to what extent the national industry is internationally competitive. In the minicomputer area, it is behind the East Asian NIEs because of its policy of market reserve, which has supported the development of a thriving yet internationally uncompetitive industry. In some other areas, such as automated banking terminals and telecommunications, Brazil is ahead of the East Asian city−states and, in a few products, perhaps even ahead of Korea and Taiwan (China). In most areas of consumer electronics, it is clearly behind Korea and Taiwan (China)—even though it sought to develop that sector with the strong participation of foreign sub−

sidiaries. The main problem is that the government forced the consumer electronics industry to locate in the middle of the Amazon, for regional development objectives, and thereby imposed great transport and infrastructure costs on the industry.

Elements of Successful Strategies

Before attempting to draw out some lessons, it is instructive to contrast the strategies followed by the large quasi−continental economies of Brazil, China, and India with those followed by the economies of Korea and Taiwan (China), on the one hand, and with those followed by the city−states of Singapore and Hong Kong, on the other.73 Perhaps because of their larger internal markets, the quasi−continental economies have been much more domestically oriented. Yet, except for that of Hong Kong, production in the much smaller Asian NIEs is considerably greater than in the quasi−continental economies (Table 16.3), and the Asian NIEs' products are almost uniformly more competitive. The reason is dearly their strategy of focusing on export markets to overcome the limitations of their small domestic markets. The export thrust also has placed the smaller East Asian NIEs in direct contact with rapid changes in global technologies and markets, thus providing incentives and know−how to respond competitively. Lest it be thought that an export orientation, as opposed to a domestic orientation, is dictated just by smaller market size, it should be noted that Japan, which has a much larger internal market than the quasi−continental economies, also adopted a strong and successful export orientation.

Also, the quasi−continental economies generally have a more targeted approach and have given a much greater direct role to government than have the four Asian NIEs (Tables 16.1 and 16.2). An important factor has been that in their targeting, the quasi−continental economies have focused too broadly and have hurried to develop the whole electronics industry based on import substitution. The Asian NIEs instead have focused more narrowly and have progressed sequentially—from production of components and assembly for foreign consumer electronics to production of components and simple consumer electronics by their own national firms, and then to production of computers and more sophisticated electronics products and components—as their experience grew.

Finally, regarding government's role and the strategies in Korea and Taiwan (China) compared with those elements in the two Asian city−states of Singapore and Hong gong, the main differences have been the smaller role of government in Singapore and Hong Kong in providing trade protection, using government procurement, or activating an industrial organization strategy—and especially the more open attitude toward direct foreign investment. Although the electronics industry in both Hong Kong and Singapore thus has developed in a much less planned way than in Korea and Taiwan (China) and is more narrowly focused, that development has followed a sequence determined more by foreign firms making use of the comparative advantage of producing there than by government. However, as noted, government has had a greater role in Singapore than in Hong Kong, and many would attribute Singapore's better performance to that more active role of the state in promoting the move toward higher−technology industry.

Some of the lessons that may be inferred from the experiences reviewed in this chapter include the following:

First , the key aspect of a successful industrial strategy, in this case for electronics, appears to be a combination of protection and nurturing during the initial phase of development, but at the same time *demanding improved performance* . The latter has been achieved primarily by forcing firms to compete abroad, but also by encouraging strong domestic competition. This is the essence of success for Japan and the East Asian NIEs.74 Conversely, extended protection without demanding improved performance has been the main reason for the uncompetitiveness of the industry in Brazil, China, and India.

The *second* lesson is that a *focus on export markets* is important not only for competitive pressure but to achieve economies of scale. High fixed costs of research need to be amortized over as large a production base as possible. The larger cumulative production made possible by export markets leads to dynamic learning since more experience is required in production. A strong emphasis on exports opens up a window on new technology and market trends, which is crucial in a sector as dynamic as electronics.

This leads to the *third* lesson, which is the importance of *continuous access to foreign technology* . Because technology is changing so quickly in electronics, and because no economy, not even that of the United States, is fully autonomous in technology, firms must be aware of and draw on the advances being made by others. Furthermore, because foreigners often are not willing to license their technology, it may be necessary to open up the domestic industry to foreign investment in or−

der to have access to that technology—not necessarily the total openness of Hong Kong and Singapore, however. The success of Japan and Korea has to some degree been related to the strategy of developing strong domestic firms.

The *fourth* lesson involves *selectivity* . It is possible to target the electronics sector too broadly, which is part of the problem with the approaches of India, Brazil, and China. If an economy is to target a sector, being selective in targeting and expanding only as capability builds up is important. The hard part of this, however, is deciding what to target. Even some developed economies have not been too successful in targeted efforts. For example, in spite of diverse government efforts in France to create a national champion to compete with IBM in computers, this strategy was not successful.

A *fifth* lesson highlights the *importance of the general economic environment and the flexibility of capital and labor markets* , particularly for dynamic sectors, such as electronics. Enough risk is inherent in the speed of technical change and increased international competition; unstable macro policies and poor growth prospects impose an unreasonably high burden on planning and competing effectively. A healthy macroeconomic environment and prospects for growth also appear to be important in order to stimulate research and investments in modern plants and facilities. This seems to have been particularly important in the cases of the United States and Japan as well as in the rapidly growing East Asian NIEs.

A *sixth* lesson is that the *role of government changes as an economy matures* . There are market failures, and some economies have developed institutions to help bridge those market failures: the conglomerates in Korea, government coordination and guidance in Japan, and the nurturing research infrastructure in Taiwan (China). However, as can be seen clearly in the experiences of Japan and Korea, government's role eventually diminishes: active at the beginning of an industry's development, but reduced influence as firms and institutions mature. The electronics industry came to rely mostly on the private sector as it developed its own capability without government intervention.75

A *seventh* lesson is that the *electronics industry should not be viewed as an end, but rather as a means to increased efficiency and competitiveness* . Seen as an end in itself, electronics development tends to lead to creation of inefficient capacity, as in the computers subsector in India and Brazil. This also opens up the issue of production versus use. As Flamm (1989) has emphasized, the main returns in computers come from their use in the economy as a whole, not their production.

An *eighth* lesson is that *governments have not succeeded alone* . Success has depended on many circumstances, including the level and quality of technical human resources, the quality of the supporting technological infrastructure, and the dynamism and quality of management and entrepreneurship in the private sector. More general conditions, such as the quality of macroeconomic management and the flexibility of capital and labor markets to adjust to changing conditions, also affect the prospects for success. However, disentangling cause and effect is difficult in assessing to what extent government intervention has led to success.

Finally, it must be kept in mind that the role of the government will depend not only on its own capabilities but also on the level of skills and capabilities in the productive sector and on the opportunities in the international environment. What may have been feasible for one economy at a particular time may not be readily replicable by another at a later time. Thus, for example, the strategy of entering the electronics industry through simple assembly for export based on low−cost labor, as was initially done by the East Asian NIEs, may not be viable now. First, the industry is much more developed and already relies on established suppliers for the simpler components. Second, low−cost labor is not that much of an advantage anymore because rapid technical change involving increased automation has reduced the importance of labor as a share of total cost. Third, being an effective competitor in the world market goes beyond low production costs to high quality and rapid delivery times. Both require more quality consciousness and institutional and support infrastructure (such as efficient customs, transportation, and communications services) than most new entrants may have.76

Four Key Roles of the State

The above summary, having raised again the issue of the state's role in the development of the electronics sector, points to four roles on which there is likely to be general agreement:77

(a) *To develop appropriate technical human capital* . Technically trained people who can follow and assess the rapidly changing technologies of the electronics industry are essential in developing an economy's capability to participate effectively in the growth of this sector. This raises the question of what types and levels of techni−cal human resources should be trained and how. Unfortunately, there still are no clear answers to this question, and further research is warranted on this topic.

(b) *To strengthen the basic technological infrastructure* .

One key element of technological infrastructure is ensuring access to information and technology and disseminating it locally. This can take many forms, ranging from bargaining (as was done extensively by national firms in the early phase of the development of the Japanese electronics industry), to providing specialized institutions to help collect, monitor, assess, and diffuse technology.

A second important element of technological infrastructure is basic metrology, standards, certification, and testing facilities, which help to ensure quality control and diffusion of technological knowledge. Here the government has an important role in establishing the institutional structure to set necessary measurement standards and certification procedures, and in helping to finance the establishment of some of the basic measurement and advanced testing facilities; equipment often is too expensive for individual firms to invest in.

A third element is providing some degree of research infrastructure to help local industry assess the relevance of technological advances and help local firms acquire technology. In Korea, public R&D institutes have helped firms bargain for access to foreign technology (for VCRs and microwave ovens). In Taiwan (China), the public R&D institute was instrumental in setting up semiconductor fabrication capability in the economy. As the local industries' capabilities mature, research may evolve to develop special new applications of technology or even to develop new technology. However, the important point is that at all times the focus of the research institutes needs to be on serving the needs of the productive sector rather than on trying to develop technology for its own sake.

(c) *To provide the right incentive regime to stimulate firms to improve their technological levels* . In the early phase, this may involve some nurturing so that firms are able to acquire technology. But nurturing has to be combined with performance requirements, especially for exports. Japan and Korea have been perhaps the best at combining these two. In the area of R&D this is also linked to the issue of intellectual property rights. There has to be some guarantee that firms that develop new technology will be able to maintain ownership of that technology so that there will be sufficient incentives for investment in R&D. In addition, adequate intellectual property right protection may be necessary to induce some foreign investors to transfer advanced technology.

(d) *To provide an environment for flexible adjustment to production structure* . This was found to be one of the most important elements for successful adjustment in a recent comparative study of economic performance among OECD economies.78 Although this holds as a general proposition, it is particularly important for a sector as dynamic as electronics. Precisely because of that dynamism, there is a premium on flexibility and rapid responses to changing technology and competition. Government has an important role in helping to develop some of the necessary institutions, including training and capital market institutions, besides the basic technological infrastructure already mentioned above.

Some Remaining Issues

There is less consensus, however, on some issues—the principal one being the desirability or appropriateness of *targeting* . Targeting can be of two types: (a) defensive targeting based primarily on protecting the sector through such instruments as trade barriers (tariffs, quotas, and "voluntary" export restraints), government procurement preferences, and "buy national" policies; and (b) positive targeting based on supporting the industry through R&D, investment, and special training incentives. It should be noted that in the economies of both the United States and Hong Kong, both of which have followed the least interventionist approach to the development of their electronics sectors, pressures are increasing for more targeting and government support. Whether targeting is chosen by the United States, and how broad its coverage might be, will have implications for developing economies.

However, regardless of whether the United States begins any type of targeting in electronics, it is significant that there is now such an active debate on the merits of targeting. Such interest has been a reaction to the perceived success of the more targeted approaches of other economies, most notably that of Japan, and indicates a growing belief that the electronics sector is strategic and that government plays an important role in its development.

One of the critical issues here is how best to identify which sectors to target. Particularly in the United States, judging the importance of some of the new technological areas is difficult. Making targeting choices is thus risky because of the uncertainty inherent in new areas. Nevertheless, distinguishing leader from follower strategies is again important. In the United States, the debate is really more about supporting national industry in the development of new technologies, not about follower strategies. The issue for developing economies, however, is much more about targeting according to follower strategies. As indicated previously in this review, follower strategies are easier, provided that the underlying technologies do not change radically. The key is to select the right niches and sequencing to build cumulatively from the easier to the more complicated. It should also be noted that the degree of government involvement in directing or targeting a sector should not be independent of the administrative capability of the government and the quality of its civil service. Also, it should be remembered that targeting has both direct and indirect costs. The direct costs are the special incentives that may be given to the targeted industry. The indirect costs are the additional costs or lower quality products the users have to bear as the targeted industry learns to produce. These are often larger than the direct costs, especially when the targeted subsector fails to become competitive.

Another issue is *sequencing versus leapfrogging* , closely related to issues of incremental versus radical change. It is possible to work on sequential incremental change as long as there is interconnectedness. When the change is very radical, the advantages of sequencing are vitiated. Knowing more about connectedness is necessary, and about whether the learning along one technological trajectory is transferable to another. Some evidence, for example, suggests that what is important is not so much the experience with different vintages of specific technologies, since these may require different skills, but with learning how to make products of different levels of complexity. Thus, learning how to produce, say, audio cassette recorders may be useful before going into the production of VCRs, which are much more complex and much more demanding.

Regarding the relevance of exports as a key element of a stratcgy to develop the electronics sector, an emerging issue is to what extent exporting might need to be reexamined in the context of the possible closing of export markets. A unified EC market in 1992 may be accompanied by the erection of trade barriers, a concern already fueled by new local−content requirements (e.g., the diffusion step of wafer fabrication). There is also some concern that the world may be moving toward regional trading blocs, which could determine and limit an economy's trading options. More generally, if the world trading system deteriorates, economies may have to rely more on internal or regional markets than on international ones. This will have different implications for economies with small internal markets than for those with relatively larger internal markets because of the economies of scale necessary for efficient production.

Finally, there is an emerging concern with the issue of *access to technology* . In addition, there is concern that privatization of standards in the electronics industry may be closing up, which may make it more difficult for developing economies to plug into electronics products trade. Some evidence indicates that accessing the newest technology through licensing is getting harder. In addition, there is much greater emphasis, especially by the United States, on intellectual property rights, with patent infringers pursued more actively and forced to settle infringement claims. It is also now more difficult to "reverse engineer" technology, especially in the electronics sector. One of the principal ways around this is for developing−economy firms to enter into strategic alliances with developed−economy firms. Nevertheless, only a handful of firms from developing economies have succeeded in entering such alliances.79 However, for firms in developing economies to do this, they have to become stronger technologically, which means governments and firms are having to invest more in their own technological capability in order to bargain more effectively for access to newer technology.

Notes

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1. This distinction between leading and strategic is based on Richard R. Nelson, *High Technology Policies: A Five−Nation Comparison* , Washington, DC.: American Enterprise Institute, 1984.

2. See Organization for Economic Cooperation and Development (OECD) 1987, *Structural Adjustment and Economic Performance* . Paris: (OECD) and Richard R. Nelson, *op. cit* .

3. An example of a successful DOD program was the spinoff from the Minuteman missile system in the 1950s, which funded Texas Instruments' research on integrated chips (ICs) and helped set up Motorola. In the 1960s, the whole development of C−MOS and N−MOS came from NASA programs. (Personal communication from Arnold Miller.)

4. Direct foreign investment restrictions in the United States have been limited to a few cases. For example, in the proposed acquisition of Fairchild Industries by a

Japanese company, it was argued that Fairchild's products were vital for national security.

5. See Kenneth Flamm, *Targeting the Computer: Government Support and International Competition* , Washington, D.C.: Brookings Institution, 1987 for an extensive analysis of the role of government in the development of computers in the United States, Japan, and Europe.

6. Venture capital was most important during the 1960, and 1970s. It was gradually supplemented by public offerings relying on the large U.S. capital market.

7. Its budget is about $60 million a year.

8. See David Mowery and Edward W. Steinmuller, "Government Policy and the Development of the U.S. Semiconductor Industry: What Lessons for Newly Industrializing Economics?" OECD Development Center Technical Paper no. 25. Paris: OECD, October 1991.

9. Three government agencies also participate in the Semiconductor Research Corporation (SRC), which is the semiconductor industry's research consortium. SRC funds silicon based research in universities in order to ensure sufficient graduates with skills that can be used by U.S. industry.

10. The difficulty that U.S. firms have in working jointly toward strategic objectives is illustrated most strongly in the recent failure of U.S. Memories. U.S. Memories was a consortium of U.S. system manufacturers who wanted to integrate backwards into the production of DRAMs in order to assure domestic supply as a counter to dependence on foreign suppliers. However, the consortium was not able to get sufficient finance or purchase commitments from other component users to make the project viable.

11. This and all other data on number of firms and employment in the electronics sector for different countries is from *Yearbook of World Electronics Data* , Volumes I and 2, Oxford:Elsevier Advanced Technology, 1991.

12. They were used even earlier in the 1950s to help consolidate the development of the Japanese consumer electronics industry, but were phased out by the 1960s when that sector became internationally competitive.

13. Kenneth Flamm, *op. cit* ., pp. 152−53.

14. MITI's Electrotechnical Laboratory (ETL), National Telephone and Telegraph's (NTT) laboratory, and those in national universities.

15. For example, IBM had to license some of its technology and limit its sales in the Japanese market. However, IBM remained the largest computer company in Japan until it was surpassed by Fujitsu in 1981.

16. Japanese companies such as NEC and Hitachi formed joint ventures with foreign firms. Only Fujitsu decided to develop computer technology on its own, and it became the head of the first cooperative research association funded by MITI. In response to IBM's 360 System introduced in 1964, MITI organized the super

high−performance computer projects (SHPCPs) that pooled resources of government labs and private corporations. In 1968 NTT also launched a major project called the DIPS information processing system computer which also involved contracting with local Japanese companies. During this period government support therefore came from its research labs as well as through conditional loans and consigned payment for contractual development of technologies by private firms.

17. Kenneth Flamm, *op. cit* ., p. 131−43.

18. Kenneth Flamm, *op. cit* ., p. 145.

19. Richard R. Nelson, *op. cit* ., p. 49.

20. The United States reacted with the formulation of a DARPA strategic computer program, the United Kingdom with the Alvey program, and the EC with the European Strategic Program for Research and Development in Information Technologies (ESPRIT) program.

21. U.S. Congress, Office of Technology Assessment (OTA) Report. *International Competitiveness in Electronics* , Washington, D.C.: Government Printing Office, 1983 p. 403.

22. For example, 90 percent of the government orders for computers were given to ICL in the 1970s as a way to help develop that firm. See U.S. Congress, *op. cit* ., p. 402.

23. U.S. Congress, *op. cit* ., p. 405.

24. The government is estimated to have poured as much as $0.7−1.0 billion into CII' through 1982.

25. Honeywell Bull was a descendant of Machines Bull after General Electric was bought out by Honeywell. With the merger, CII−HB became a majority−owned state company but was nationalized in 1982.

26. This paragraph draws heavily on U.S. Congress, *op. cit* ., pp. 394−400.

27. For a more detailed assessment of EC activities and experience see G. Vickery, "Latecomer Strategies in Advanced Electronics−Lessons from the European Experience." OECD Development Center, Technical Paper. Paris: OECD, 1991.

28. The five designated areas are advanced microelectronics, computer−aided design manufacturing, software, office systems, and advanced information processing.

29. Unlike ESPRIT, EUREKA is not an EC institution governed directly by the European Commission. It is governed by a weak secretariat the includes non−EC countries such as Sweden.

30. Unlike the EC projects such as ESPRIT, they focus more on advanced development than on basic research, are more company directed, and have more flexible funding structures than the 50 percent grant typical of the EC projects.

31. See Kenneth Flamm, "Trends in Manufacture and Use of Electronics: Implications for LDCs' Strategies." World Bank, Industry and Energy Department, Industry Development Division, Washington, D.C. Processed 1990 for more details.

32. This section draws on material prepared by Mario Ripper (1989) and on C. Frischtak, Chapter 13 of this book.

33. Starting in 1973 Telebras began to sponsor applied research projects to ensure that Brazil would be prepared to take advantage of major breakthroughs in telecommunications technology, including digital pulse code modulation systems, time division multiplexing systems, and stored program controlled exchanges. Most of these research projects were contracted out to university research groups, though some went to private companies.

34. By 1988 it had 400 professionals in R&D and a budget of about $60 million.

35. Frischtak (Chapter 13).

36. Frischtak (Chapter 13).

37. Frischtak (Chapter 13).

38. The government has only one 100 percent state−owned company (Cobra) which produces superminis, minis, and personal computers (PCs), and has less than 10 percent of the total sales of Brazilian companies.

39. Developing the Amazon region is linked to strategic military considerations of occupying Brazilian national space in what was a vast underpopulated region.

40. Electronics exports consist mostly of automobile radios and cassette players made by Philco (Ford) and Volkswagen, and of some large computers by IBM as part of export commitment agreements.

41. In use of IT products per 1,000 persons, the intensity in Brazil is low compared with the that of East Asian NIEs. Scaled by million GDP, however, the pattern changes. Brazil turns out to be intensive in televisions per $1 million of GDP, but low in computers.

42. This section is based on World Bank (June 1989), *China Electronics Sector Report* , World Bank Report No. 7962, Washington, D.C.

43. The section on India draws heavily on Geoffrey Gowen and Daniel Hefler, Chapter 14 of this book.

44. The Indian government unsuccessfully tried to force IBM to sell a majority share of its Indian operation in 1960. However IBM decided to close up shop and leave rather than to divest majority ownership. Restriction on royalty payments and other limitations have also turned away more sophisticated technology in many areas.

45. A World Bank study of the Indian electronics industry in June 1987 suggested the following additional policy changes: progressively eliminating quantitative restrictions on imports and further reducing tariffs; simplifying and eventually eliminating the Phased Manufacturing Program which encourages uneconomic levels of local content; eliminating remaining restriction on technology imports; extending capacity delicensing to industrial electronics, computers, and telecommunications; removing remaining dominant firm clearance requirements for products where scale is needed for efficiency; and easing restrictions on exit of inefficient firms. See Chapter 14 of this book.

46. It is quite competitive in some segments of software, however, due to the low cost of Indian engineers.

47. The growth of consumer electronics has been led by the assembly of televisions which is being based increasingly on domestically manufactured components.

48. In 1987 the first three had sales of 21, 14, and $13 billion, respectively, and were among the 35 largest non−U.S. industrial corporations in the world as reported by *Fortune* magazine, August 1988.

49. See Tibor Scitovsky, "Economic Development in Taiwan and South Korea: 1965−1981. *Food Research Institute Studies* 19(3):223−64, 1985 and Leroy Jones, "Jae−bul and the Concentration of Economic Power in Korean Development: Issues, Evidence, and Alternatives." In II SaKong, ed., *Macroeconomic Policy and Industrial Development Issues* . Seoul, Korea: Korea Development Institute, 1987.

50. See Ashoka Mody, Chapter 15 of this book, for a fuller development of this argument. Note, however, that the advantages of conglomerization must be weighted against the diseconomies of excessive vertical integration.

51. A fifth company, Korea Electronics, also fabricates wafters.

52. World Bank 1987. "Korea: Managing the Industrial Transition," Washington, D.C.: World Bank.

53. Ashoka Mody, "Institutions and Dynamic Comparative Advantage: Electronics Industry in South Korea and Taiwan." World Bank Industry and Energy Department Industry Series Working Paper 9. Washington, D.C. Processed, 1989.

54. Korea is the second largest producer of VCRs and microwave ovens in the world (after Japan) and the third largest producer of DRAMs.

55. The two largest local electronics firms, Tatung and Shampo, formed joint ventures with Japanese partners. The larger is Tatung, with 1984 sales of $500 million (compared with Korea's Samsung with $10 billion in the same year, of which $2 billion was in electronics). Tatung dominates the production of monitors. It is an original equipment manufacture (OEM) supplier for the IBM PC and has had a long relationship with IBM.

56. MOEA identified the scope of strategic industries under the criteria of "two highs (high value added and high−technology intensity), two bigs (big linkage effect and big market potential), and two lows (low pollution, and low energy intensity)." Yeo Lin, "Industrial Technology Policy in Newly Developed Industrial Countries: The case of Taiwan," 1988, processed.

57. San Gee, "The Status and an Evaluation of the Electronics Industry in Taiwan." OECD Development Center Technical Paper no. 29. Paris: OECD, October 1989.

58. Yeo Lin, *op. cit* .

59. Unlike Korea, the government has been much more open to foreign firms. This policy, not applicable to the electronics sector alone, seems related to a certain distrust for big business, perhaps carried over from the days of Sun Yat−sen.

60. Two of the companies set up in the park, Acer and Mitac, had 1988 sales of $380 million and $293 million, respectively. They were two of the only three developing country companies among the top 50 non−U.S, information services companies in the world, in the yearly list complied by *Datamation* .

61. Based on Yeo Lin, *op. cit* .

62. The telecommunications equipment industry (other than telephones) is also not particularly competitive. The main reason appears to be that it has been overregulated for national security reasons. Much civilian telecommunications equipment is not allowed to be produced or marketed. As a result, that subsector has the largest technological gap among the electronics industries with respect to the international frontier. See San Gee, *op. cit* .

63. Taiwan's semiconductor industry started in 1966 with the establishment of a plant by General Instruments (a U.S. company to assemble transistors). By the end of the decade, several other foreign companies, including Texas Instruments and Philips set up semiconductor assembly plants based on imported components.

64. Yeo Lin, *op. cit* .

65. Philips started with a 25 percent equity stake in TSMC. Besides transferring its 2 micron technology, Philips guaranteed that until domestic demand was large enough it would feed the output through its own international supply network. This allowed TSMC to produce

at the high volumes required for economic efficiency from the very beginning. Phillips may also increase its equity stake to 51 percent and move a large−scale manufacturing project with Siemens to Taiwan (China).

66. One of the first eight−bit computers produced by ACER was designed with help from ERSO. ERSO also helped develop clones for the IBM PS2, new 80846 designs, RISC alliances and the brand new field of add−on cards.

67. San Gee, *op. cit* .

68. Ashoka Mody, "Institutions and Dynamic Comparative Advantage: Electronics Industry in South Korea and Taiwan." World Bank Industry and Energy Department Industry Series Working Paper 9. Washington, D.C. Processed, 1989.

69. This was done by imposing a tax on lower−skill activities, coupled with many programs to increase the skill levels of workers through on−the−job training. There has also been a significant increase in formal education oriented to the higher technical and engineering areas, especially electronics. Forty percent of all students enrolled in higher education are in engineering.

70. This effort was led by senior officials from the NCB, the Economic Development Board (EDB), and the National University of Singapore (NUS).

71. The government, through the EDB, has pioneered some very innovative programs with foreign governments and foreign companies to train workers in critical IT−related areas. Foreign companies such as NEC and IBM enjoy special incentives and even special grants to train more people than they need in critical areas.

72. James Riedel, *The Industrialization of Hong Kong* . Tubingen, the Netherlands: JCB Mohr. 1974.

73. This characterization of Brazil, China, and India as quasi−continental economies is taken from Ernst Dieter and David O'Connor, "Technology and Global Competition: The Challenge for Newly Industrializing Economies.' OECD Development Center Study. Paris: OECD, 1989.

74. See, in particular, the discussions in Alice H. Amsden, *Asia's Next Giant: South Korea and Late Industrialization* . New York: Oxford University Press, 1989, chapters 3−5 and Carlotta Perez, "Electronics and Development in Venezuela: A User−Oriented Strategy and its Policy Implications." OECD Development Center Technical Paper no. 25. Paris: OECD, October 1990.

75. However, in some other OECD economies, the role of government has been substantially increasing, and targeting has become a fact of life in many of these economies. See David Teece, "The Nature of Support Policies for Strategic Industries," *OECD Forum for the Future* , Paris, OECD, 1990.

76. For a fuller development of these arguments, see H. Hakanson. *Corporate Technological Behaviour: Cooperation and Networks* , London, 1990.

77. Similar key roles for the state have been identified by Dieter Ernst and David O'Connor, *op. cit* .

78. See OECD 1987. *Structural Adjustment and Economic Performance* . Paris: OECD.

79. In Korea, for example, Samsung has a strategic alliance with Intel and Hyundai with Texas Instruments, both for memory chips; and Daewoo with Zymos for ASIC. In Taiwan (China), for example, Acer has alliances with Texas Instruments. See Dieter Ernst, "Network Transactions and Technological Capabilities−Implications for North−South Cooperation," Paris: OECD, 1990 and Dieter Ernst and David O'Connor, "Competing in the Electronics Industry—The Experience of Latecomers." OECD Development Center. Paris: OECD, 1991.

Annex
Public Policy Workshops

Arnold Miller, Debra L. Miller, and Denis F. Simon

In 1987, the World Bank organized a three−week seminar on the electronics industry for senior government officials of China. The 30 participants were high−level decisionmakers, representing the Ministry of Electronics Industry (MEI), regional electronics bureaus, and a number of Chinese enterprises and institutes. To give the participants a picture of the worldwide electronics scene that covered the market, technology, public policy, and comparative country studies and experiences, some 40 experts in electronics and industrial policy from industry, industrial consulting firms, academia, government, and the World Bank presented lectures and participated in discussions. The seminar emphasized the dynamics of the interaction between technology, the market, and policy. A series of public policy workshops was carried out during the last two days of the seminar, which allowed the participants to discuss how to apply the new material presented during the previous sessions to deal with strategic issues and options in the development and operation of a viable electronics sector in China.

This kind of policy workshop training has broad application to the development of the industrial sector in developing countries. This annex sets out both the techniques and the context of the workshops as a guide for future seminars of this type.

Content

There were three separate sets of workshops, each set taking two−thirds of a day. Each participant took part in a total of three workshops, one from each set. The composition of each of the workshop teams was determined early in the first week. The workshop discussion agendas had been used to guide discussions during the seminar. In some of the groups, the selection of participants was based on interest group, such as regional bureau officials, enterprise or institute managers, or ministry officials. In other cases, the participants in the individual teams represented a cross−section of interests. Some of the speakers at the seminar participated in the workshops as resource persons.

The workshops had a common format. Each workshop had a Chinese leader/rapporteur designated by the participants. In all cases the workshop organizers encouraged the participants not to automatically select the most senior member of the individual team as a workshop leader. Prior to the workshops, each participant received a one−page agenda of items to be discussed during the workshop and a description of the output expected. The leader/rapporteur focused the group on the task they had to complete, for example, a simulated subsector strategy plan. While discussion was limited to one and a half hours per workshop and the participants had half an hour to complete their specific task, as the groups had been established some three weeks earlier, the participants actually spent considerably more time thinking through and discussing their task. This extended time is deemed to have been essential. On completion of the group tasks, the participants reconvened. Each leader/rapporteur made a fifteen−minute presentation to the entire group on the outcome of their specific workshop, and discussions followed.

The workshops were organized into three sessions. Each session addressed the following substantive issues:

Session I

Three concurrent workshop groups were set up. One dealt with the MEI directors' common concerns about formulating strategic plans in the electronics sector and developing policies that would help develop the sector. Another workshop dealt with the common concerns of the leaders of the regional electronics bureaus about formulating strategic plans for the sector and the issues and problems in carrying out national plans formulated by the MEI, while still being responsive to local needs. The third workshop addressed the common concerns of enterprise and institute leaders about formulating strategic plans for their entities' operations and the subsequent development of implementation plans. The leader/rapporteur for each group gave a report based on the group's discussions of the issues involved in making policy and planning development in the electronics sector.

Session II

The second set of workshop groups was organized along subsectoral lines. Participants examined trends in their subsector; its current state of development in China; medium−term production goals given subsector's state of development and Chinese products' potential for international competitiveness; appropriate policies to aid the subsector's development; and suggestions for fostering links to avoid redundancy among regional bureaus, firms, and R&D institutes. The leader/ rapporteur for each group presented a subsector development plan for consideration by all the participants.

Session III

The third set of workshop groups focused on critical issues in the electronics sector. Topics included (a) acquiring technology, renovation, innovation, dissemination plans and policies, and technological infrastructure development; (b) becoming competitive in international trade; and (c) fostering links among R&D institutes, industry, and government to promote innovation, commercially−oriented research, and a strong national technological infrastructure. The leader/rapporteur's report for each group was based on the discussions about the respective critical issues in the electronics sector, identified key problems, and suggested alternative solutions.

The purpose of the workshops was to synthesize the new material the participants had learned during the seminar with their own experiences and knowledge. The overarching issue addressed was what China should do and what it requires in view of the new information obtained. Open discussion was promoted. In several instances, individuals changed their views and approaches as the discussions continued. In every case the seminar's organizers encouraged participants to avoid stock answers and conventional wisdom and challenged the participants to examine the assumptions underlying their particular views.

Observations

Substantive concerns in any one area were raised again and again during the workshops. Some of these areas surprised many of the participants themselves, who apparently had not focused or verbalized these issues beforehand. An interesting interplay occurred within the group discussions where one regional manager could solve another regional manager's problems. Throughout attempts were made to have agenda questions and support material reflect current issues in China, not theoretical problems and situations. The workshop agendas are given at the end of this annex.

The workshops in **Session I** were concerned with the formulation and implementation of strategies. What are strategies? How is strategy formulated? How are issues and policy complementarities dealt with? Participants found out that strategy is not itself the objective, nor is it simple planning. Strategy is not short range, ad hoc, or opportunistic. Strategy is the establishment of programs to achieve specific goals. Participants examined prevailing industry structures and economic factors that preclude given strategies. They raised the question of how much structural change the economy could accommodate.

The regional organizations are the bridge builders between the central government and individual enterprises. Participants from these organizations examined the amount of freedom of choice and maneuverability really available at the regional level. This led to consideration of central government limits and their impact on alternative solutions, and raised the questions of how this balance between the center and the regions might vary from region to region, and how regional competition could be dealt with in strategy formulation at the bureau level.

The participants from enterprises discussed the extent to which their enterprises are allowed to function as economic units as opposed to administrative units. They have to deal with managers getting mixed signals both from the regional level

and the national level. The managers pointed to taxation policies placed on the enterprises versus redistribution approaches and how this affected their ability to operate. They went head−on into the question of conflicts between enterprise objectives and the accomplishment of given national goals. During the Session I workshops the participants realized that the diagnosis of problems and the choice of alternatives depends on their position in the system.

The **Session II** workshops focused on subsectoral strategies as elements of the strategy for the entire electronics sector. One of the objectives was to show the various parts of a sectoral plan, the importance of each part, and the interrelationships among the parts. At one point, a subsectoral plan was found to be impossible to implement because of the inappropriate requirements placed on collateral subsectors outside the control of the subsectoral planner.

The discussions highlighted the need to look at subsector's interdependencies, because plans, strategies, and goals must be feasible from the total system's point of view. The requirement that subsectoral planners must be able to state the requirements for collateral subsectors so as to develop rational implementation strategies for their own subsector came up again and again. Interestingly enough, this was not a self−evident requirement.

The discussions invariably got back to specific goals and objectives and the necessary strategies to realize them. Implementation planning took on a special significance. The complementarity and conflicts among exports and domestic demands were highlighted, but how they might be reconciled was not truly addressed. Slowly, participants clarified and defined the unique resources necessary to achieve subsectoral goals.

The **Session III** workshops built upon the discussions about common concerns and subsectoral strategies, and boiled down to the basic question of how China could become competitive in the electronics sector. How can China improve its performance in electronics regarding cost, quality, and technology? The workshop organizers stressed that one cannot consider these questions on a purely theoretical basis. They must be examined within the context of an industrial and planning structure for electronics as discussed in Session I and the subsectoral plans discussed in Session II.

The first group of this session focused on technology acquisition, particularly on the relationships between electronics sector strategies and specific policies for technology development and transfer. The participants examined China's absorptive capacity and the current strategies' ability to incorporate programs that increase this capacity. They discussed linkages between technology transfer and indigenous R&D programs and stressed selection criteria. As part of the group's output, they were asked to outline their goals for imported technology and their priorities in light of their subsectoral plans and strategies.

The second group in this session addressed the issue of China's current position in the international electronics trade and its strengths and weaknesses. Specific policies to remedy the weaknesses and to promote the strengths were defined.

The third group dealt with the establishment of links to create a strong technological infrastructure among research institutes, universities, and enterprises. The participants discussed the importance of, and need for, such links and specified the goals for cooperation. This led to defining what is expected of enterprise zones. Finally, they examined the kinds of policies needed to make meaningful a strategy for developing China's technological infrastructure.

In retrospect, an important product of the seminar, and of the policy workshops in particular, was to facilitate (indeed, in many cases, to initiate) discussions among the Chinese participants and between them and the resource persons that continued well after the seminar had concluded.

Agendas

The following are summaries of the agendas handed out to the policy workshop participants.

Session I Agendas

Session I is divided into three workshops:

1. Common concerns of the MEI directors about formulating strategic plans in the electronics sector and developing policies that will help develop the sector;

2. Common concerns of the leaders of the regional electronics bureaus about formulating strategic plans for the sector and the issues and problems in carrying out national plans formulated by the MEI, while still responding to local needs;

3. Common concerns of enterprise and institute leaders about formulating strategic plans for their operations and the subsequent development of implementation plans, with an emphasis on the flow of relevant work from institute to enterprise.

The purpose of this session is to illuminate your common concerns regarding the development and implementation of strategy at the national, regional/municipal, and enterprise levels.

A. Strategy Formulation

1. What is the essence of China's strategy as seen from your perspective?

2. In the development of strategies in your work, how are alternative approaches developed and evaluated and selections made? How do you choose between alternatives? What are the more important factors influencing ultimate choices? What interactions occur during the process with others in the electronics industry as well as with other groups?

B. Strategy Implementation and Policy Complementarity

After the choice of an electronics strategy, policies need to be reviewed to ensure that they will promote the achievement of the strategy. An appropriate mix of policies (financial, commercial, science and technology, investment) is important for further progress.

1. What policies are important to achieve your strategic goals? What means do you use to implement these policies? What are the barriers to obtaining the required resources (financial, human, energy, and so on) for your work?

2. Discuss any contradictions among existing policies and how they could be remedied to promote the strategic goals.

3. Discuss the current incentive and reward system created by existing policies. Is the system consistent with the goals of the strategic plans? Do they favor near−term at the expense of long−term priorities? Do they allow for experimentation and some failure?

4. How does the structure of your industry influence your choice of implementation plans? In what way is it supportive? Restrictive? Is it appropriate for carrying out your job? What degree of organizational flexibility do you have to meet new goals and objectives? Is there appropriate feedback? Does the structure determine the goals?

C. Other Common Concerns

What other types of common concerns do you have that have not been touched upon? How are you dealing with them in your endeavors?

The product of the workshop is the identification of common concerns and the suggestion of alternative solutions.

Session II Agendas

Session II is divided into three subsectoral workshops: 1. Computers and telecommunications; 2. Consumer electronics, and 3. Components and industrial electronics.

A. Production Issues

Given the state of the means of production, what are realistic near−term and medium−term production goals for the subsector? What are the sources of technology for the subsector? Acquisition mode? Alternatives? How is training provided? What provisions are made for adequate inventory control, shop floor control, production planning, manufacturing information systems, and quality control? How are supplier networks developed?

B. Policy Issues

What are the explicit government policies (for example, education and training programs, research and design centers, technology extension and information services, standards and metrology services, technology transfer and patent regulations, financing mechanisms for industrial technology development) that will have an impact on the development of this subsector?

How can these policies be improved with a view to the development of the subsector? How can regional and national planning be rationalized in this subsector?

C. How can China Foster Links Among Government, Industry, and R&D Institutes so as to:

Provide policy improvements,

Reduce redundancy among regional production efforts and achieve an interdependent approach to subsectoral development,

Promote the relevance of R&D institutes' work to manufacturing and training without transforming them into manufacturing concerns,

Finance cutting−edge technology research that will also have commercial relevance?

The product of the workshop is the development of a medium−term subsectoral strategic plan.

Session III Agendas

Session III is divided into three critical issues workshops:

1. Acquiring technology, innovation, dissemination plans and policies, and technological infrastructure development;

2. Becoming competitive in international trade;

3. Fostering links among universities, R&D institutes, industry, and government to promote innovation, commercially−oriented research, and a strong national technological infrastructure.

Critical Issue 1

A. Technology decisions:

What factors are considered in deciding on technology transfer? What are the pertinent technology import strategies and what policies affect technology transfer? What are the selection criteria for the choice of technology? How is the make or buy decision made?

B. Technology search/acquisition:

What are the mechanisms to define and select candidates? Where are the sources of suitable candidates determined? What are the alternatives available for receipt of and payment for technology acquisitions? Are there others to be considered?

C. Technology acquisition management:

How do you organize to manage the project? How are the milestones and performance criteria measured and monitored? What are the criteria for success of the project, both long−term and short−term goals? What have you learned from prior management experiences?

D. Innovation:

What are the Chinese training and employment practices to engender/defeat innovation? What are the incentives for making innovations to existing technologies?

E. Dissemination:

What infrastructure is needed to engender dissemination of technologies? What are the incentives and disincentives for dissemination of technology?

The product of the workshop is the identification of problems in each of these issue areas and the suggestion of alternative solutions to the problems.

Critical Issue 2

A. Studies of the electronics industry in other countries have shown that several factors (listed below) contribute to a country's export capabilities. Discuss current Chinese policies in each of these issue areas and how they could be improved to enhance China's export capabilities.

1. The achievement of appropriate scales of production and associated efficiencies.

2. The adequate provision of information services to policymakers and producers, including marketing analysis and intelligence and overall environment/competitor analysis for both the regional and global markets.

3. The determination of the country's comparative advantage in the particular sector or subsector. Components of comparative advantage include technical superiority, organizational superiority, product quality, diversity of product lines, and market access. In which of these areas is China's electronics sector strong? Weak? How could the strengths be enhanced and the weaknesses remedied?

B. The choice of an appropriate mix of macroeconomic, commercial, and investment policies is important in fostering an environment designed to promote exports. The following are especially important:

1. After the choice of a trade strategy, macroeconomic policies should be reviewed to ensure that they will promote, not hinder, the strategy (for example, although import substitution has some benefits, it can detract from export pro. motion). In other words, policies must complement one another.

2. An appropriate mix of incentives for exporting and for servicing the domestic market.

3. Internal competition among both domestic and foreign firms must be fostered to develop higher quality and lower priced goods, while at the same time promoting the growth of Chinese firms.

In each of the above areas, discuss the extent to which Chinese policies are both satisfactory and complementary. If policy contradictions exist, how could they be remedied?

C. The advent of the computer has revolutionized manufacturing processes and spurred the development of worldwide sourcing in the electronics sector.

1. How does your industry currently use computer−aided design, computer−aided management, computer−aided manufacturing, and automated machinery?

2. Is it feasible for your industry to increase its use of these tools to promote its export capability in electronics?

The product of the workshop is the identification of problems in each of these issue areas and the suggestion of alternative solutions to the problems.

Critical Issue 3

1. Discuss briefly the policy and working links among government, industry, and the scientific academic community in other countries (such as India, Japan, Korea, the United Kingdom, and the United States).

2. What are the important characteristics and dynamics of such relationships? What have been some of the important products of these relationships (such as the creation of research and manufacturing, manufacturing−related innovation, and lack of redundancy in research and production)?

3. What is the present situation in China regarding these relationships? What are the areas in which China is succeeding in these relationships? Having problems?

4. How could China overcome some of these problems?

5. Given the discussions of items 1 through 4, develop a feasible strategy for cooperation among government, private industry, and academia; the goals of such cooperation; and the possibilities for developing research zones in China.

The product of the workshop is the identification of problems in each of these issue areas and the suggestion of alternative solutions to the problems.

ABBREVIATIONS AND GLOSSARY

A

ABINEE Electronics Industry Association, Brazil

AEA American Electronics Association, U.S.

AMPS advanced mobile phone services, a standard cellular mobile technology

Analog any form of information transmission where the signal is measured continuously (as opposed to digital)

ASIC applications−specific integrated circuits

ASP average selling price

Aspect ratio the width−to−height ratio

ATM automated teller machines

B

Beta a VCR system proprietary of the Sony Corporation, Japan

Bipolar a semiconductor device that uses both positive and negative charge carriers

Bit a binary digit, the smallest unit of information

BMFT Bundes Ministerium Fuer Forschung und Technologie, German ministry for research and technology

Board level an aggregate of devices and their interconnections contained on a printed circuit board

BPO British Post Office, the former U.K. government branch that provided postal and telecommunications services; its telecommunications operations later became British Telecom, now privately owned

BRITE Basic Research in Industrial Technologies for Europe; a European Community program for basic research in advanced communications technology that funds R&D on industrial manufacturing technologies and advanced materials applications

BT British Telecom, the largest telecommunications operating company in the U.K.

Byte a group of binary digits used as a measure of storage and transmission to represent a character (i.e., an 8−bit byte)

C

C−DAC Center for the Development of Advanced Computing

CAD computer−aided design

CAE computer−aided engineering

CAM computer−aided manufacturing

CCD charge−coupled device

CCIR *Comite Consultatif International de Radio* , an organ of the ITU dealing with radio communication standards

CCITT *Comite Consultatif International Telegraphique et Telephonique* , an organ of the ITU dealing with voice and data communication standards and operations

CD compact disc

CD−ROM compact disc read−only memory, a high−density optical storage system

CDOT Center for Development of Telematics, India

Cell library collection of standard functional unit designs that are compatible for use in complex ASIC product development

CEN European standards committee

CENELEC European committee for electrotechnical standardization

chaebol in Korea, a very large, highly diversified business conglomerate under a common controlling ownership; as a group, chaebols account for a large part of the economy, particularly industry

CIM computer−integrated manufacturing

Clean room facility used in semiconductor fabrication with controlled environment (e.g., dust, humidity)

CMOS complementary metal oxide semiconductor

CNC computer numerically−controlled, as used in machine tools

Codec coder/decoder used in electronics and communications

COMECON Council for Mutual Economic Assistance, the now−defunct economic organization of Eastern Europe and the Soviet Union

CPE customer premises equipment, such as telephone sets, fax machines, modems, and PBXs

CPqD *Centro de Pesquisa e Desenvolvimento* , the center for telecommunications research and development operated by TELEBRAS, Brazil

CPU central processing unit, the heart of a computer that controls its functions and operations

CRADA Cooperative Research and Development Agreement, U.S.

CRT cathode ray tube, such as the picture tube in TV sets

CTI *Centro Tecnologico da lnformatica* , informatics research center under Brazil's Ministry of Science and Technology, modeled after CPqD

CTO chief technology officer

D

DARPA Defense Advanced Research Projects Agency, U.S.

DAT digital audio tape

DBS direct broadcast satellite

DFI direct foreign investment

DGT *Direction Généale des Télécomunications* , the French government's department responsible for telecommunications policy and regulation

Digital any form of information transmission where the signal is measured at discrete intervals and represented by a series of encoded pulses; this is the basis for all current telecommunications and computer technologies

DOC Department of Commerce, U.S.

DOD Department of Defense, U.S.

DOE Department of Electronics, India

DOE Department of Energy, U.S.

DRAM dynamic random access memory

DSP digital signal processing

DTA domestic tariff area

E

EC European Community

ECL emitter coupled logic

ECU European Currency Unit

EDB Economic Development Board, Singapore

EDI electronic data interchange

EDP electronic data processing

EFTA European Free Trade Area

EFTS electronic funds transfer service

EIA Electronic Industries Association, U.S.

EIAJ Electronic Industries Association, Japan

EPABX electronic private automatic branch exchange

EPROM erasable programmable read−only memory

EPZ export processing zone

ERSO Electronics Research Service Organization, sponsored by ITRI, Taiwan (China)

ERTA 1981 Economic Recovery Tax Act, U.S.

ESPRIT European Strategic Programme for Research and Development in Information Technologies, a 10−year program launched in 1986 to make the EC more competitive in information technology

ETL Electrotechnical Laboratory, run by MITI, Japan

ETRI Electronics and Telecommunications Research Institute, formerly KETRI, Korea

ETSI European Telecommunications Standards Institute

EUREKA European research cooperation agency; promotes cooperation on technology R&D among the countries of the EC, EFTA, and Turkey

F

FDM frequency division multiplex

FERA Foreign Exchange Regulation Act, India

FET field effect transistor, normally using MOS technology

FGTS *Fundo de Garantia de Tempo de Serviço* , Brazil

Function a combination of electronic components and their interconnections that perform a specific operation

G

GaAs gallium arsenide, a material used in the manufacture of semiconductor devices

GAO General Accounting Office, U.S.

Gate array an integrated circuit device containing a regular assemblage of logic elements (gates), with interconnection determining the end application and performance of the device

GATT General Agreement on Tariffs and Trade

GDP gross domestic product

GEICOM interministerial group for components and materials, Brazil; created in 1975 to increase domestic content, establish programs for technology transfer and development, and standardize the production of equipment, components, and materials

G one billion (one thousand million) units, as in gigabits and gigabytes

GNP gross national product

H

HCL Hindustan Cables Limited, India

HDTV high−definition television, a generic term denoting the new color TV systems featuring much higher picture definition and sound quality

High−Vision HDTV standards officially adopted by Japanese transmission equipment manufacturers in 1984; they incorporate NHK's system for encoding HDTV signals

I

I/O input/output (device)

IC integrated circuit, a large number of interconnected electronic devices fabricated on a silicon substrate

ICICI Industrial Credit and Investment Corporation of India

ICL International Computers Limited, India

ICOT Institute for New Generation Computer Technology, Japan

IDBI Industrial Development Bank of India

Informatics emerging field combining computer and information services with telecommunications, data processing, broadcasting, publishing, and related activites

III Institute for Information Industry, Taiwan (China)

IPO initial public offering

ISDN integrated services digital network, which allows image, voice, and data signals to be transmitted on the same line

ISTEC International Superconductivity Technology Center, Japan

IT information technology

ITC International Trade Commission, U.S.

ITI Indian Telephone Industries

ITRI Industrial Technology Research Institute, Taiwan (China)

ITU International Telecommunication Union, the intergovernmental UN agency for telecommunications standards, radio spectrum allocation, and development

J

JECC Japan Electronic Computer Company

JESSI Joint European Submicron Silicon Institute, a part of EUREKA

JIPDEC Japan Information Processing Development Center, created in 1967 by MITI to market software and provide training

JIT just−in−time manufacturing process

JSIA Japanese Semiconductor Industry Association

K

KAIST Korean Advanced Institute of Science and Technology

K one thousand units, as in kilobits and kilobytes

KETRI Korea Electronics and Telecommunications Research Institute, now ETRI

KIET Korean Institute of Electronics Technology

KIST Korean Institute of Science and Technology, merged in 1981 with the Korean Advanced Institute for Science to form KAIST

KTAC Korea Technology Advance Corporation

KTS key telephone systems

L

LAN local area network

LCD liquid crystal display

LED light−emitting diode

Line of code a unit of symbolic representation of computer program instructions

LISP an artifical intelligence computer software language

Logic gate a circuit performing a logic function through control of a binary signal

LSI large−scale integration

M

µ micron, unit of measure equal to one one−millionth of a meter; also used to denote one millionth of any other unit of measure, such as µF (one millionth of a Farad, measure of capacity)

MAC multiplexed analog components, standard for television signal delivery agreed by members of the EC

Maquiladoras Mexican plants that benefit from U.S. and Mexican laws to reduce direct labor costs in the assembly phase of manufacturing

MAP Microprocessor Applications Project, United Kingdom; funds 25 percent of the costs of product development to incorporate microprocessors in manufactured products

M one million units, as in megabit and megabyte

MCC Microelectronics and Computer Technology Corporation, a 25 member consortium focusing on the broad applied development of computers, software, semiconductor packaging, and design

MEI Ministry of Electronics Industry, People's Republic of China; merged in 1988 with the Ministry of Machine Building to form MMEI

MES minimum economic scale

Microcomputer small computer that uses a microprocessor and memory to process and store information

Micron technology semiconductor microelectronic miniaturization as represented by the line widths used in the device (e.g., 3µ technology); the smaller the dimension the more advanced the technology

Microprocessor computer processor unit contained on an integrated−circuit chip

MIS management information system

MISP Microelectronics Industry Support Program, U.K.

MITI Ministry of International Trade Industry, Japan

MMC Monopolies and Mergers Commission, U.K.

MMEI Ministry of Machine Building and Electronics Industry, China

Modular electronic an electronic assemblage using interconnected standard modules in its manufacture hardware

MODVAT modified value added tax, India

MOEA Ministry of Economic Affairs, Taiwan

MOS metal oxide semiconductor

MPU microprocessor unit

MRTP Monopolies and Restrictive Trade Practices Act, India

MS−DOS a computer disk operating system that is proprietary of Microsoft Corporation, U.S.

MSI medium−scale industry

MUSE multiple sub−Nyquist encoding, a bandwidth compression technique

N

NAFTA North American Free Trade Association, the free trade treaty among the United States, Canada, and Mexico

n nano, one billionth of a unit measure, as in nanosecond

NCB National Computer Board, Singapore

NCR a U.S. computer manufacturer

NEC Nippon Electric Company, a Japanese manufacturer of computers and telecommunications equipment

NHK Nippon Hoso Kyokai, the Japanese public broadcasting and TV system

NIE newly industrialized economy, usually referring to Hong Kong, Korea, Singapore, and Taiwan (China), and more recently also to Brazil, Malaysia, Mexico, Thailand, and other emerging industrial economies

NIST National Institute of Standards and Technology of the Department of Commerce, U.S.

NMOS negatively−doped metal oxide semiconductors

NMT Nordic Mobile Telephone, a standard cellular system in use in Scandinavia and Finland

NRI nonresident Indian

NTIS National Technical Information Service, U.S.

NTSC National Television Systems Committee, after which the U.S. color television standard is named

NTT Nippon Telephone and Telegraph Corporation, the largest Japanese telecommunications operating company

NUS National University of Singapore

O

OECD Organization for Economic Cooperation and Development, comprising all Western industrial countries and Japan

OEM original equipment manufacturer

OGL open general license, India

OS/2 a proprietary computer operating system developed by IBM

OSI open systems interconnection

OTA Office of Technology Assessment, U.S.

P

PABX private automatic branch exchange

PAL phase alternation line, the color television standard used in most western European countries

PAL programmable array logic

PBX private branch exchange

PC personal computer, a low−cost microcomputer; rapid successions of generations achieve ever−increasing memory capacity and processing power

PCB printed circuit board

PCM pulse code modulation, the basic technique for encoding information in digital form

PDA personal digital assistant

Photonics technology that processes large amounts of digital information through fiber−optic cables

PIS/PASEP *Programa de Integração Social/Programa de Assistencia ao Servidor Publico* , Brazil

pixel picture element, the number of which determines the maximum definition of an image, as on a TV or computer monitor screen

PLANIN national informatics plan, Brazil

PRC People's Republic of China

PROM programmable read−only memory

PSE public sector enterprise

PTT post, telephones, and telegraphs ministry or state enterprise; usually refers to situations where this entity is both the operator and the policy and regulatory arm of the government

Q

QCD quality, cost, and delivery

QCDST quality, cost, delivery, service, and technology

QR quantitative restriction

R

R&D research and development

RACE Research on Advanced Communications in Europe, and EC program

RAM random−access memory

RBI Reserve Bank of India

RCA revealed comparative advantage

REP replenishment export license, India

RISC reduced instruction set computing, a type of computer architecture

ROM read−only memory

S

S&T science and technology

SDI Strategic Defense Initiative, U.S.

SECAM the color television standard used in France and certain Eastern European countries

SEI *Secretaria Especial da Informatica* , the agency that implements the Brazilian informatics law

SEMATECH Semiconductor Manufacturing Technology, a semiconductor development consortium of companies, U.S.

SHPCP super high−performance computer project, organized by MITI, Japan

SIA Semiconductor Industry Association, U.S.

SMD surface−mounted device

SME semiconductor manufacturing equipment

SPC stored−program control, a common technique of telephone switching

SRAM static random access memory

SRC Semiconductor Research Corporation, a 34−member consortium of companies that funds directed university research, U.S.

SSI small−scale industry

T

TDMA time−division multiple access

TELEBRAS *Telecomunicacoes Brasileiras S.A.* , the state−owned public telecommunications holding company of Brazil

TI Texas Instruments Inc., U.S.

TNC transnational corporation

TRON Real−Time Operating System Nucleus, a Japanese R&D project

Tropico project undertaken by CPqD in Brazil to develop digital switching equipment for small and medium−sized public telephone exchanges

TSMC Taiwan Semiconductor Manufacturing Company

TTL transistor−translator log, an electronic logic circuit

U

UHF ultra high frequency (300−3,000 MHz)

UNIX computer operating system designed by Bell Telephone Laboratories, U.S.

U.S.AID Agency for International Development, U.S.

U.S.ITC International Trade Commission, U.S.

V

VAN value−added network

VCR video cassette recorder

VHF very high frequency (30−300 MHz)

VHS a proprietary VCR format of Japanese Victor Corporation

VHSIC Very High Speed Integrated Circuit, a program formulated by the U.S. Department of Defense for military applications

VLSI very large−scale integration or integrated (circuit)

VSAT very small aperture terminal, a technology for low−traffic satellite communication

W

Wafer silicon substrate of varying diameter used in semiconductor processing

WAN wide area network (telecommunications)

Work station a personal computer with a high memory and processing power, normally used by professionals

Z

Zaibatsu in Japan, a conglomerate of companies often with a high degree of vertical integration including suppliers, banks, and trading companies, not always with formal owner−ship links

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