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Baseline Assessment of the Semiconductor Industry

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AUTHOR: Ronald G. Bechtold

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INTENDED AUDIENCE: Those who have an interest in the buyer-seller relationships and the structure of the semiconductor industry.

BRIEF SUMMARY: For the first twenty-five years after the invention of the transistor, the United States dominated the world semiconductor market. This preeminence was due to a combination of favorable government support, a robust US economy, lack of foreign competition, and good luck.

The industry has experienced a profound change since the late 1970s. The United States, still a major world supplier, is no longer dominate. Changing government influence, a battered US economy, the rise of foreign competition, and a lack of national consensus contributed to this change.

The phenomenal increases in productivity in this industry have contributed to the growth of the US economy and the superior quality of military weapons. Semiconductors have become so commonplace and so integrated into many segments of the economy that they represent a major national asset.

This paper traces the historical development of the semiconductor industry to understand the present industry structure, its conduct, and performance. Based on an analysis the major industry trends and their implications, this paper identifies policy recommendations for government and industry.

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Executive Summary

For the first twenty-five years after the invention of the transistor, the United States dominated the world semiconductor market. This preeminence was due to a combination of favorable government support, a robust US economy, lack of foreign competition, and good luck.

The industry has experienced a profound change since the late 1970s. The United States, still a major world supplier, is no longer dominate. Reduced government purchases, a battered US economy, the rise of foreign competition, and a lack of national consensus contributed to this change.

The semiconductor industry is not at risk. The loss in market share is part of the natural forces of competition. Past management complacency and a large domestic market masked the impact of foreign competition and thus led to a reduction in US dominance of semiconductors. The changes in the world market would have occurred in any case. The transition period is not over and more consolidations are probably necessary to reduce excess capacity and improve profitability.

The phenomenal increases in productivity in this industry have contributed to the growth of the US economy and the superior quality of military weapons. Semiconductors have become so commonplace and so integrated into many segments of the economy that they represent a major national asset. They are the building blocks for the $384+ US electronics industry--the largest US employer.

There are many complex interrelationships among the semiconductor industry, its related industries and US infrastructure. Therefore, simple prescriptive policy recommendations to enhance the competitiveness of the US semiconductor do not exist.

The White House needs to accept these realities and develop an industrial strategy to restore business confidence, to increase the supply of scientists and engineers, to maintain a stable monetary policy, and to remove all regulatory policies which inhibit firms from seeking long-term business strategies.

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Chapter 1

Introduction

This report on the Semiconductor Industry assesses the economic vitality of the industry in terms of its market structure, conduct of firms, and economic performance. The technological innovations of this $21 billion US industry have fueled the growth and productivity of the $384 billion US electronics industry--the largest manufacturing industry in America[1]. Figure 1 shows the contribution of semiconductors to the US manufacturing and service economy. The National Advisory Committee on Semiconductors estimates that by the year 2000 world demand for semiconductors will be about $200 billion. This creates many opportunities for US industry. The US can exploit these opportunities, if it can maintain a healthy semiconductor industry to successfully compete in this growing world economy.

Semiconductors: A Foundation for Preeminence

Industries	United States 1990	World 1990	World 2000
Total Manufacturing and Service Economy	$5.4T	$20T	$40T
Electronics Products and Serivces	$384B	$751B	$2T
Semiconductor Manufacturing	$21B	$63B	$200B
Semiconductor Materials & Equipment	$9B	$20B	$60B

Fundamental Sciences and Processes are the linchpins for continued growth. These include: Software, Gases and Chemicals, Optics, Materials, and Robotics.

Source: Adapted from National Advisory Committee on Semiconductor, Dataquest, and American Electronics Association

Figure 01.

Semiconductors are also vital to defense, since they are increasingly an important part of weapons systems. Yet, there are disturbing trends--excess production capacity, shrinking world market share, and fluctuating profitability. This report describes these industry changes--and factors driving those changes.

The federal government played a vital role in the development and early growth of the semiconductor industry, but this role has diminished. Present National Security priorities dictate a declining defense electronics budget. This, however, does not prohibit DoD from acting as a catalyst by providing incentives for R&D, encouraging industry cooperation and expanding the supply of scientists and engineers.

This assessment is presented in the following chapters:

1) a review of the evolution of the semiconductor industry from 1947,
2) a description of the semiconductor industry
3) an assessment of the major linkages of the industry,
4) a summary of the conduct of selected firms in the industry,
5) an examination of government's influence in shaping the conduct of firms,
7) evaluating the industry using Michael Porter's model,
8) a review of the performance of semiconductor firms,
9) some observations,
10) recommendations for action, and
11) conclusions.

Chapter 2

Evolution of the Semiconductor Industry from 1947

Much of the present day structure of the industry is a result of policy and competitive pressures during the early stages of this industry. Therefore, this chapter will review the early years of the semiconductor industry, describe some significant trends, and look at factors which drive the industry.

The Early Years

The semiconductor industry began in 1947 with the invention of the transistor at Bell Labs--the research arm of American Telephone & Telegraph (AT&T). In the 40s, Bell Labs along with the "Big Eight" tube manufacturers[2] made up the US electronics industry. This was an oligopoly market structure, that is, one composed of a small number of sellers and buyers. This market structure discouraged entry of new firms by using patent restrictions.

In the 1950s, US anti-trust actions against AT&T triggered it to abandon restrictive business practices. This resulted in AT&T's decision to share its technology and license its transistor innovations. Thus, many new firms were able to enter the industry.

These firms had no vested interest in tube manufacturing and were therefore anxious to promote transistorized products. Tilton in International Diffusion of Technology estimated that technology change during this period reduced production costs by 40 to 60 percent and sometimes caused technology to become obsolete in as little as six months. These factors encouraged the continued influx of new firms to exploit this fast-changing technology. Texas Instruments was one of these new firms. Its later invention of silicon transistors further expanded the market by satisfying military needs for reliable, high-frequency components (see figure 2).

US Semiconductor Market Shares of Major
Merchant Firms, 1957-1966 (Percentage of Market)

Type & Name of Firm	1957	1960	1963	1966
Western Electric	5	5	7	9
Receiving Tube Firms	9	8	8	8
General Electric	6	7	5	7
RCA	5	4	b	b
Raytheon	4	3	b	b
Philco-Ford	3	6	4	3
Westinghouse	2	6	4	3
Others	2	1	4	3
Subtotal	31	36	28	28
New Firms				
Texas Instruments	20	20	18	17
Transitron	12	9	3	3
Hughes	11	5	b	b
Motorola	b	5	10	12
Fairchild	b	5	9	13
Thompson Ramo Wooldridge	b	b	4	b
General Instrument	b	b	b	4
Delco Radio	b	b	b	4
Others	21	15	24	12
Subtotal	64	60	68	83
Total	100	100	100	100

Source: International Diffusion of Technology, Tilton p,66)
Note: 'b' Not a top producer, incl in others

Figure 02.

In the 1960s, the development of new manufacturing techniques, such as the planer process, which made batch production possible and lowered cost, also caused a major shift in the market structure. Several tube manufactures, who did not adopt these new manufacturing techniques, lost market share in semiconductors. These firms left the semiconductor industry, but remained viable by designing and assembling higher value-added products which use semiconductors. The adeptness in which firms like Fairchild, Motorola and Transitron produced better quality and cheaper products led to the growth and development of the semiconductor industry. This trend continued throughout the 60s and 70s as innovations like the integrated circuit and microprocessor transformed the industry. During this period, other integrated circuit firms and most of the "Big Eight" tube manufacturers quit the business to concentrate on "down-stream" products which exploited the benefits of semiconductors.

Significant Trends

Demand patterns also changed. Titon's examination of Department of Commerce data shows that "the importance of the defense market grew ... from $15 million in 1955 to $294 million in 1968, and accounted for between one-fourth and one-half of the total market." But, the demand patterns shifted from the 60s onward as the computer industry and electronics industry became more dominate. Malerba in The Semiconductor Business described the three major trends in this industry--"...during the transistor period (the 1950s), the path was directed toward reliability and performance [military demand]; during the integrated circuit period (the 1960s) toward miniaturization [military and computer demand]; and during the large-scale integrations period (in 1970s and early 1980s) towards miniaturization and integration [military, computer,and consumer demand]" (25). These demand patterns encouraged the entry of new firms and new consumers, and the influence of the military was diluted (see figure 3).

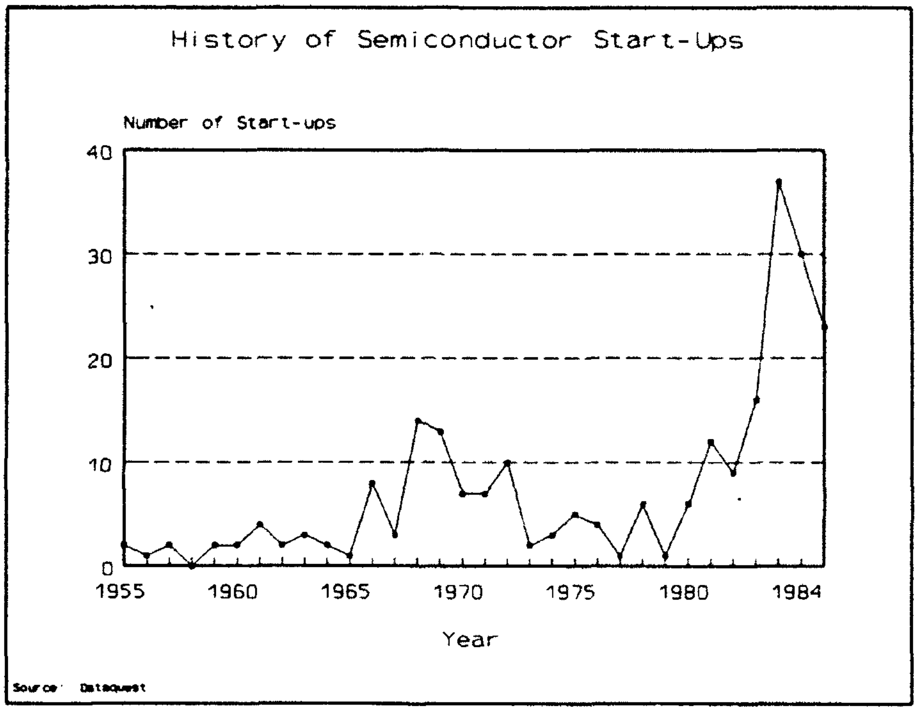
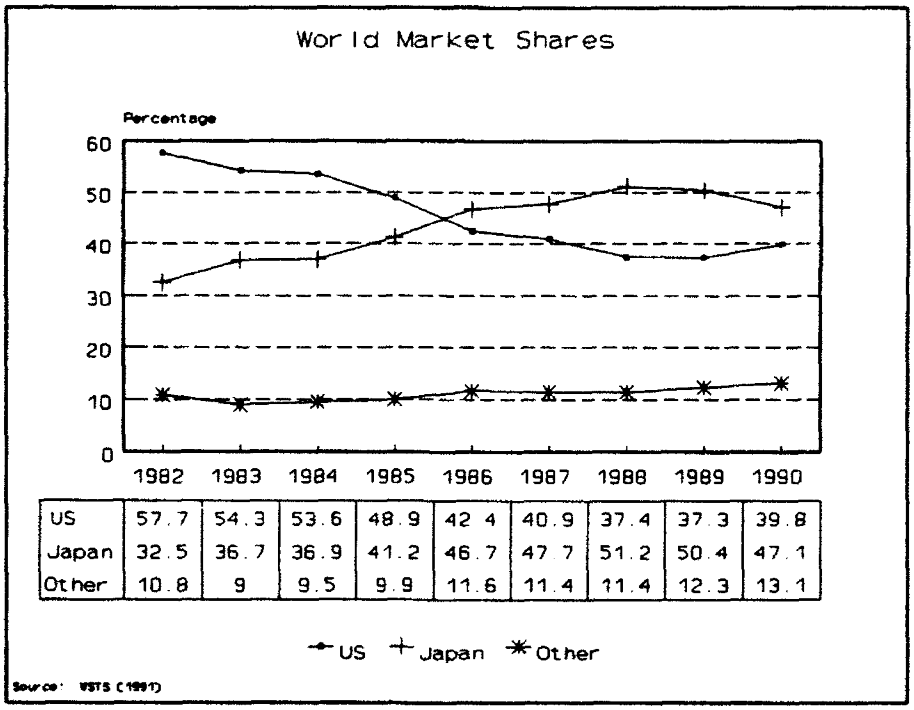


Figure 03.

Standard & Poor's latest Industry Survey relates that "The US share of worldwide merchant integrated circuits (IC) market fell to 37 percent in 1990 from 67 percent in 1980; during that same period Japan's share doubled to 48 percent from 24 percent." American leadership in the industry has declined as Japan--using US obtained licenses and concentrating on quality, reliability, and higher production yields--captured a large part of the world market. Michael Malone in The Big Score describes the dynamics of the early 80s as a period in which many US firms exited the industry via numerous mergers and acquisitions[3].

This situation quickly changed again, as once again, the introduction of new technology created the opportunity for the entry of new firms. This new process was the gate array. Malone describes the gate array as a "standardized chip whose functions could be defined by turning off or on the dozens of even thousands of separate circuits on its surface" (163). Thus, gate arrays filled a market niche as semi-customized chips at a fraction of the cost of a fully customized chip. Many of today's specialized chip firms got their start during this period.[4]

These trends continue today as high costs and rapid fluctuations in demand continue to cause firms to exit the industry; while technological innovations continue to create opportunities for new firms to enter. The US industry is holding its own (figure 4). US world market share bottomed out during the period between 1988 and 1989. Since that time US firms have made modest increases in world market share. New innovations in flash memory and state-of-the-art dynamic random access memories are leading the US recovery[5]. In addition, R&D is up. Not enough to cause a significant change in US market share, since the Japanese continue to spend twice as much as the US, but a positive trend.



	1982	1983	1984	1985	1986	1987	1988	1989	1990
US	57.7	54.3	53.6	48.9	42.4	40.9	37.4	37.3	39.8
Japan	32.5	36.7	36.9	41.2	46.7	47.7	51.2	50.4	47.1
Other	10.8	9	9.5	9.9	11.6	11.4	11.4	12.3	13.1

Figure 04.

The US still maintains a strong lead in specific segments of the semiconductor market, such as microprocessors and application-specific integrated circuits. The question is not whether the structure and conduct of the US industry today can maintain its competitive position, but how quickly it can change to meet the challenges posed by technological change, global competition, and lower risk investments.

Technology Factors which Drive the Industry

Two forces drive this industry: rapid technology change pushes new opportunities into the hands of designers and quick demand saturation pulls down the price for new technology. For example, technological advances continue to provide faster speed, lower power consumption, greater degrees of miniaturization, and better reliability. Perhaps Moore's Law[6] best captures the phenomenal success of semiconductors becoming a dominate force for rapid change. According to this law, the price for a certain unit of performance decreases about 30 percent per year. Michael Boss provides a good example of this in his article "Will industry economics defy Moore's Law?" which appeared in a Dataquest Research Newsletter. He shows how a leading-edge four megabyte chip Dynamic Random Access Memory (4Mb DRAM) has dropped in price from $460 to less that $10 in a six-year period.

This price-performance improvement has contributed to the tremendous productivity of today's electronics. Can it continue? Boss believes progress may be slowing. It now appears that economic forces--high costs of designing, marketing, and manufacturing leading-edge ICs--will slow semiconductor improvements as firms reach technical limits, such as 0.1 micron linewidths. For example, many industry experts foresee the 0.1 micron linewidths as a technical limit which will slow, if not halt, advances in miniaturization. No one really knows if the pace of rapid technological breakthroughs can continue.[7]

Past advancements in IC design created numerous opportunities for new products such as video camera recorders, smart weapons, and industrial robots. These rapid breakthroughs generate a dynamism in the industry that requires firms to innovate and quickly bring products to market. Firms that fail to anticipate change don't have sufficient time to exploit a market change.

An example is the technology movement to MOS (metal-oxide-semiconductor) from bipolar technology. Initially, firms used bipolar technology in making semiconductors. It allows circuit conduction in either direction under the influence of an electric signal. These products were fast and well suited for analog applications such as control circuits in missile technology. MOS devices, on the other hand, are unipolar operating under the control of voltage. They are slower than bipolar but are cheaper to manufacture and require less power to operate. These products are excellent for consumer goods and computers.[8]

Malerba points out that "...in the early 1970s, several Japanese firms committed considerable resources to the development and production of MOS integrated circuits" (206). They did this because US dominance of the bipolar integrated circuit market effectively excluded the Japanese industry. Malerba reports that by the mid-1970s, Japan began shipping MOS technology and by the 80s "...[Japan] captured 70 percent of the 64k RAM (1982) and 90 percent of the 256k RAM market (1984)."[9] In the 1980s US, firms failed to anticipate the advantages of MOS devices. Perhaps this is a case of defense consumption masking commercial opportunities. Thus, while the US firms developed new generations of high-performance bipolar technology for defense applications, Japanese firms looked ahead to develop MOS technology.

MOS production resulted in higher manufacturing yields, lower defect rates, and lower unit costs. The Japanese began to flood the world market with semiconductors memories built using MOS technology. This reduced the unit cost of many products built using semiconductors, such as personal computers, and thereby stimulated worldwide demand for these products. Because US firms were not competitive, worldwide market share shifted to Japan (see figure 5).[10]

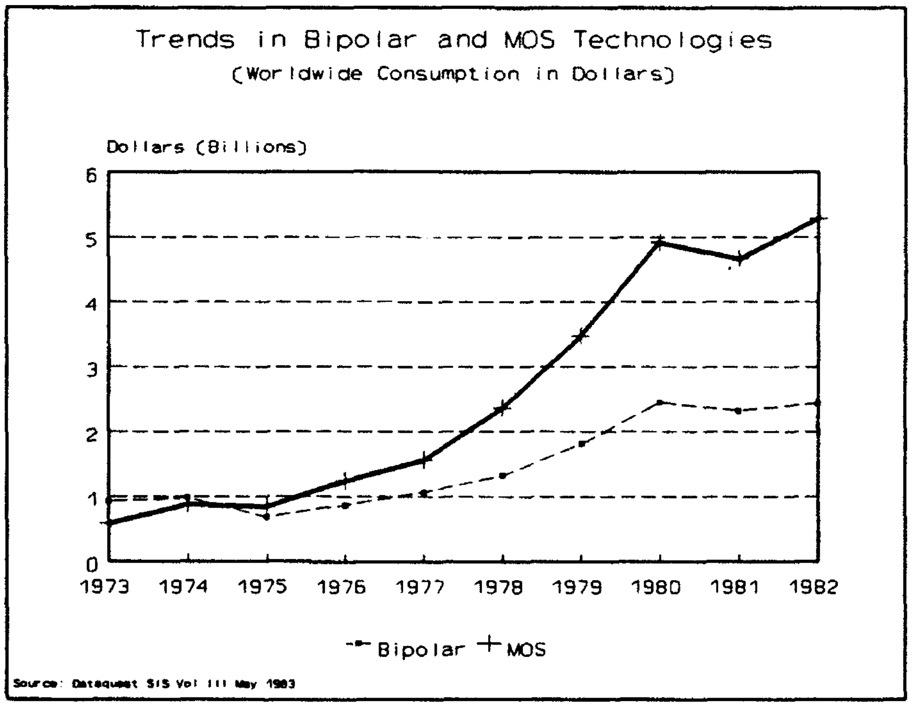


Figure 05.

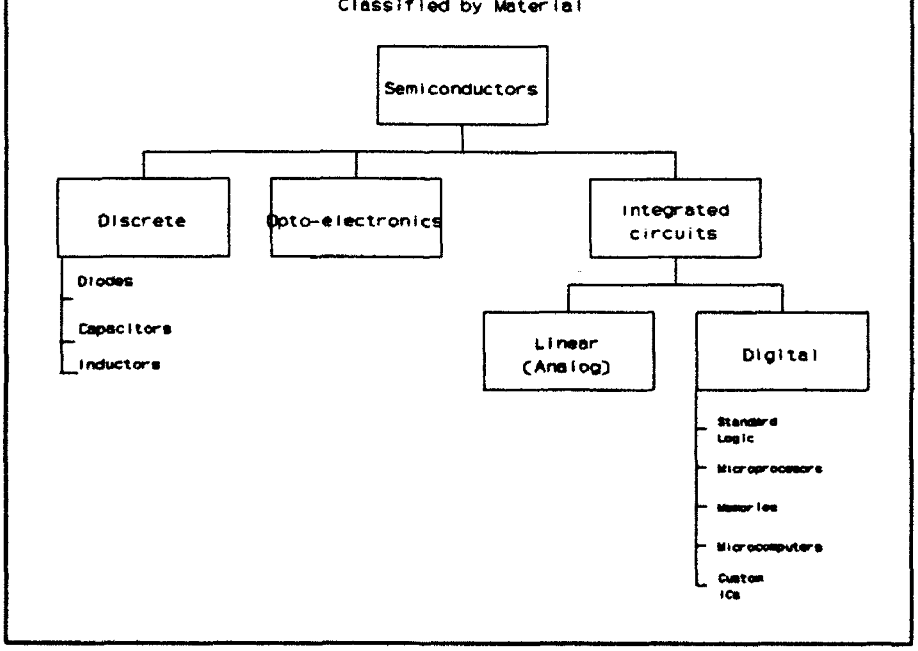
Chapter 3

Describing the Semiconductor Industry

There are many ways to describe the semiconductor industry. This section will: describe the industry using the Department of Commerce's Standard Industrial Code (SIC)--a hierarchical classification scheme, explain the industry segments in terms of product families, review the concentration of firms, look at their pricing behavior, describe market share trends and assess the industry's linkage to upstream and downstream related industries.

The Industry Described Using the Standard Industrial Code

The Department of Commerce uses a standard coding scheme to organize information about industries. The Standard Industrial Code for the semiconductor industry is 3674. Included in this industry are about 130, mostly small, US firms involved in the design and/or manufacturing of material which can function as either a conductor of electricity or as an insulator. The industry is divided into segments along product families. The major ones are: discrete components, opto-electronic devices and integrated circuits (see figure 6).



Semiconductor Taxonomy
Classified by Material

Classification of Semiconductors by Product Families

Discrete devices were the bread-and-butter of the early semiconductor industry. These are single elements of an electric circuit.[11] They are used mainly for switching functions, such as converting direct current to alternating current in electric motors, for amplification, such as enhancing electronic signals in radios and avionics, and for changing the characteristics of electronic signals, such as matching the electrical characteristics of audio speakers to match those of a stereo amplifier. Examples of predominate products in each of these categories are: diodes, transistors and capacitors.

Opto-electronic devices are recent products used in optical systems such as lasers used in compact disk recording systems and directed-energy weapons. Major devices include light-emitting diodes, photodectors and solar cells.[12]

Finally, the largest and most diverse segment is the **integrated circuits**--whole circuits of discrete devices combined on a single silicon wafer. There are various sub-classifications of these circuits. In analog circuits the relationship between the input and output varies continuously over time, while in digital circuits the relationship is binary (on/off). The three most common integrated circuit families are: memories, microprocessors and microcomputers. They are defined below:[13]

Memories are digital integrated circuits which store information. There are many sub-classifications for memories, depending on how changeable the stored information is. ROM (read-only-memory) stores information permanently unchanged. RAM (random-access-memory) allows stored information to be changed, but not permanently. PROM (programmable-read-only-memory) allows information to be programmed after manufacture, but once set it cannot be changed. There are many other classifications of memories--mostly distinguished by speed and function. These specialty areas will not be discussed here; instead, the important point to remember about memories is that most systems use a mixture of all of these types (ROM, RAM, PROM, etc).

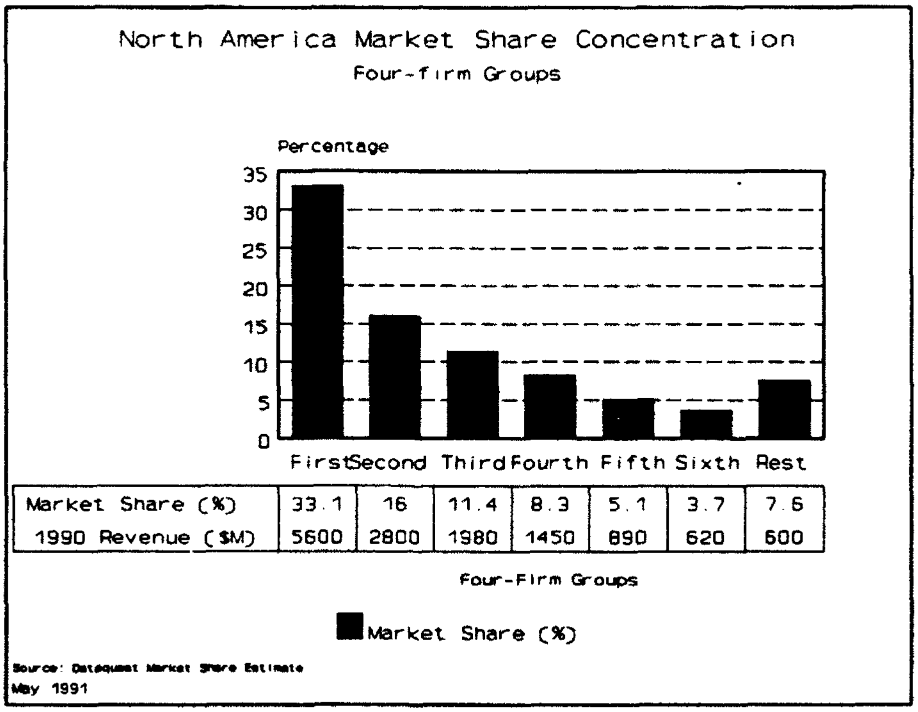
A **microprocessor** is a digital integrated circuit which can perform as the central processing unit (CPU) of a computer. It is the "brain" of the computer. A microprocessor is usually classified by the size of its "words". That is the unit of information processed. Common word lengths are 4-bit, 8-bit, 16-bit, 32-bit, etc. For example, 4-bit microprocessors are used in small appliances-like sewing machines; 8- and 16-bit microprocessors are used in video games; and 16- and 32-bit microprocessors are used in current generation personal computers and command and control systems.

Microcomputers are digital integrated circuits combined with memories. These are mainly used in high performance applications where small size is also a consideration. Examples include: laptop computers, process control and avionics.

Concentration of Firms

Examining the structure of the US semiconductor industry using macro indicators of units shipped fails to accurately portray the complexity and dynamism of the industry. For example, the US share of the North American market has dropped from 70 percent in 1988 to 68.7 percent in 1990.[14] This gives no indication of the health of the individual firms or their long-term competitiveness.

The market share concentration provides some insight into the strength and competitiveness of US semiconductor firms, but more illuminating evidence is found when viewing the concentration of market segments.[15]



	First	Second	Third	Fourth	Fifth	Sixth	Rest
Market Share (%)	33.1	16	11.4	8.3	5.1	3.7	7.6
1990 Revenue ($M)	5600	2800	1980	1450	890	620	600

Figure 07.

Dataquest Inc. revenue statistics for the North American market illustrate the market concentration: the top 20 firms in North America produce almost 75 percent of all revenue (see figure 7). There is a high degree of concentration of US firms, and therefore the industry is probably best characterized as a competitive oligopoly.[16] This type of industry structure is intensively competitive, with a small number of firms (about 10) producing a majority of the output, and the market leader setting price standards. This structure is fairly typical of many US industries such as, aviation and mini-steel mills.

Pricing Strategies

One characteristic of this structure, which creates intense competition and spurs innovations, is the pricing history exhibited by industry learning curves. The short life span of technology--three or four years--creates intense pressure for firms to be the first to bring new technology to the market place.

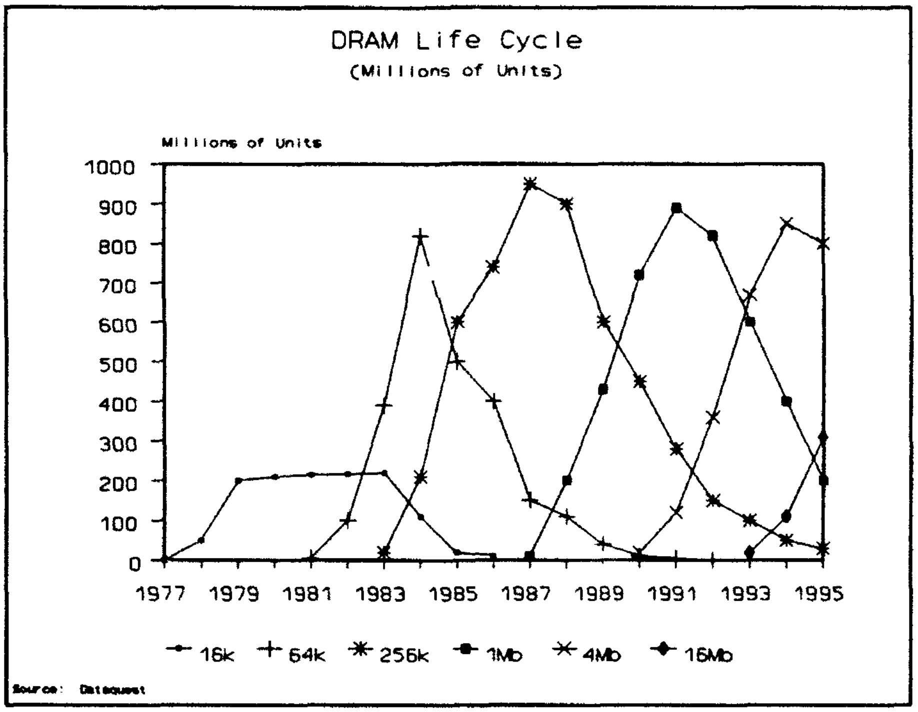


Figure 08.

For example, figure 8 shows the industry's experience for several succeeding generations of DRAMs.[17] One noticeable trend has been a quickening in the pace of succeeding generations of DRAMs. So, not only is the life span of a generation of technology short, but it's getting shorter.

Industry leaders, exploiting the oligopoly structure of the industry, establish price levels to quickly recover R&D costs.

They must do this before competition quickly drives down prices. Typically, prices fall about 90 percent within three to four years.

Figure 9 shows the industry's experience in ICs during the period 1964 through 1975.[18] This trend line indicates that for each doubling of cumulative output, the selling price in constant dollars has decreased by 27 percent. This behavior is exhibited by most semiconductor products. This enables the industry as a whole to provide increasing performance at reduced prices, thus creating tremendous opportunities for downstream suppliers to increase their productivity and sales.

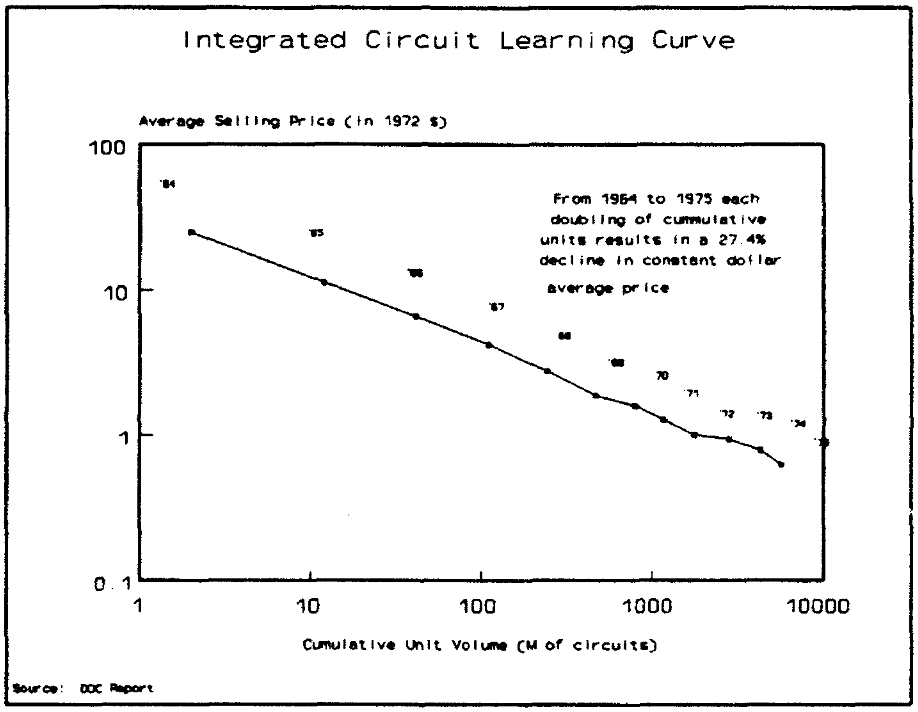
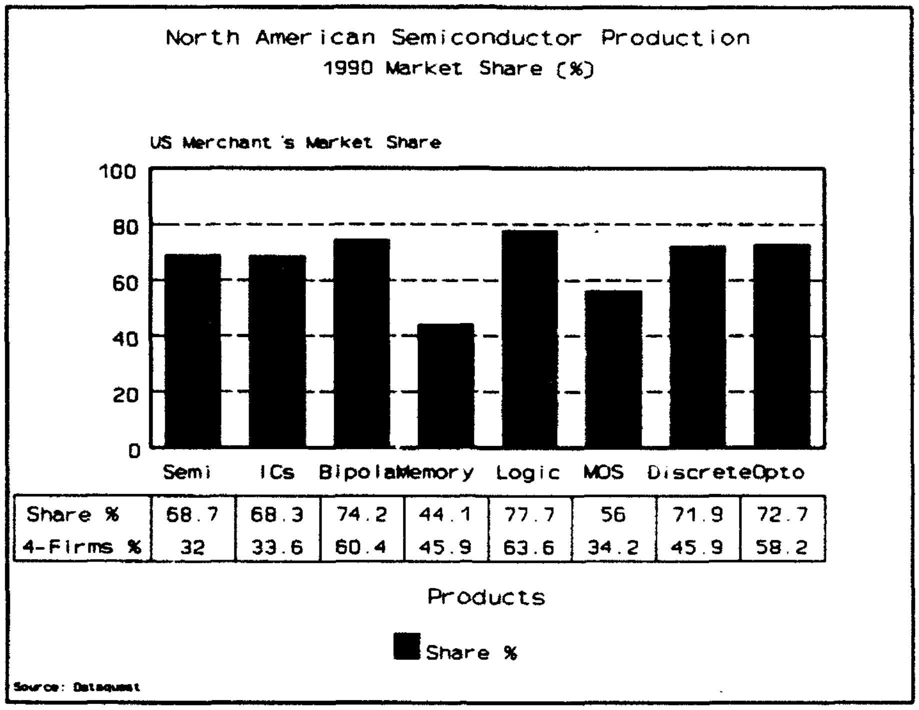


Figure 09.

Market Share Dynamics

A second and perhaps more illuminating view of the industry can be observed by looking at the market share for firms in different segments of the market (see figure 10).[19] Each of the segments of the North American market is quite concentrated. The US is very competitive in specific semiconductor segments, most notably the ICs and logic devices.



	Semi	ICs	Bipolar	Memory	Logic	MOS	Discrete	Opto
Share %	68.7	68.3	74.2	44.1	77.7	56	71.9	72.7
4-Firms %	32	33.6	60.4	45.9	63.6	34.2	45.9	58.2

Figure 10.

The major exception is memories. The US lost its lead in memories during a short time period between 1978 and 1984, when the Japanese exploited the movement to 256K DRAMs (Dynamic Random Access Memories). However, this could change quickly with a technological breakthrough. Recent announcements by IBM (16Mb DRAM) and Intel (flash memory) demonstrate that US firms are innovative and can effectively respond to competitive market pressures.[20]

The Japanese developed flash memory, but Intel improved upon their design and now controls 85 percent of this market.[21] Flash memory is a likely replacement for hard disk drives in laptop and notebook computers. In a high technology industry, leadership is fleeting without constant innovation and struggle. However, US firms have shown a remarkable resiliency to competitive pressure and remain competitive in many market segments.

Chapter 4

Major linkages in the Semiconductor Industry

Semiconductor firms impact many diverse segments of the US economy. This section will examine the major linkages by describing the upstream industries, explaining the structure of the US semiconductor industry, assessing the decline in the industry's competitiveness, describing demand trends, looking at the contributions of the US infrastructure and policy, assessing weaknesses in the US industry structure and looking at major occupational shifts.

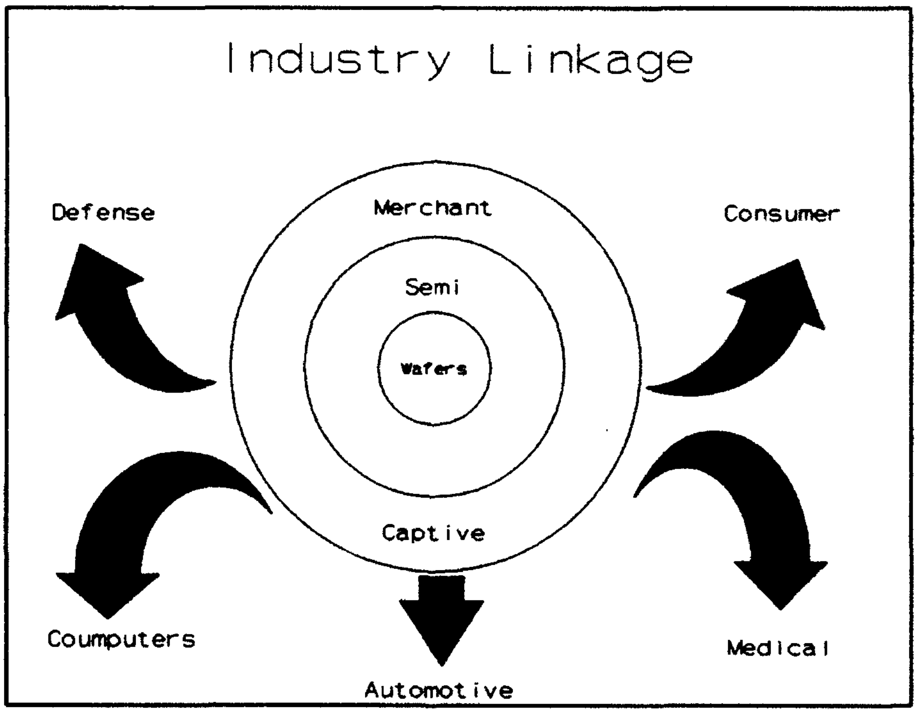


Figure 11.

Major Linkages

Figure 11 shows the major linkages among the semiconductor industry and related industries. Products in the semiconductor industry are not directly consumable by end users; instead they are included as components in many commercial, industrial and government products. These industry sectors drive the semiconductor demand curve and performance characteristics.

Upstream Industries--Wafer Manufacturing and Equipment Suppliers

The semiconductor industry is dependent upon two upstream industries--the wafer manufacturing industry and the Semiconductor Equipment Manufacturing Industry (SEMI). The first basic industry is the wafer manufacturing process. Here silicon crystals are grown, cut, and polished. The second basic industry consists of some 135 small US SEMI firms which provide a wide variety of manufacturing equipment used for building circuit designs onto the silicon wafers to produce finished semiconductor products.

Two trends in these upstream industries are noteworthy. First, almost all semiconductor wafers are produced by Japanese firms, which have refined US processes to produce high quality crystals. William H. Reed, president of Semiconductor Equipment & Materials International, recently told Congress "at one time, Du Pont, Merck, Dow Corning, Union Carbide, ... were supplying silicon to the [US] market."[22] These well-funded firms exited the silicon crystal market because of the ever increasing costs to manufacture high quality crystals and the decision by US semiconductor firms to move their production facilities overseas to offset labor costs. His conclusion, "...US companies are increasingly reluctant to invest in high-technology operations because of poor returns on these investments...."

Second, the US SEMI firms continue to lose worldwide market share. Figure 12 illustrates that the US market share has declined from 54 percent in 1987 to 47 percent in 1989. There are indications that this trend is slowing.[23] The US government sponsored a joint venture--SEMATECH--with 14 leading semiconductor firms in 1987 to improve US competitiveness in this industry. It's too early to assess whether this effort will be successful.

US Semiconductor Industry Structure

Today the top 40 US semiconductor firms produce over ninety percent of the US semiconductor production. These firms are grouped into two broad classifications--merchant suppliers and captives. The merchant producers are a unique US phenomenon. These are mostly medium-sized firms--annual earnings between $1 and $3 billion--which produce semiconductors for domestic and worldwide consumption.

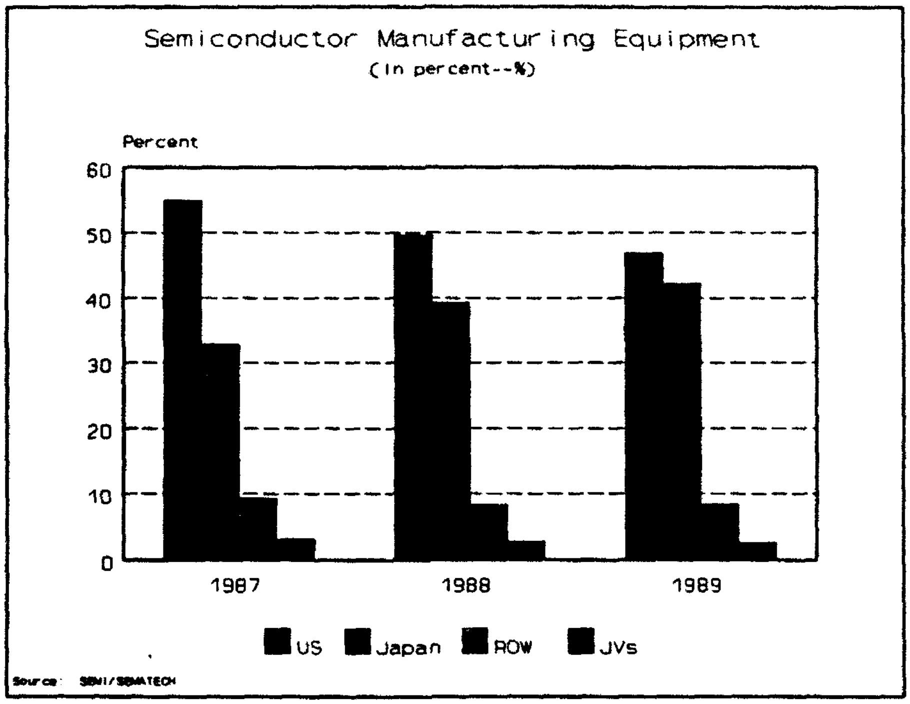


Figure 12.

Figure 13 is a list of the top-ten merchant firms based on IC sales. The captives are vertically integrated firms which produce semiconductors for their own consumption. They do this to maintain a stable supply and to maintain an understanding of the performance and design characteristics for subsequent exploitation in commercial products. Some of the more well known captives are International Business Machines, American Telephone and Telegraph and Hewlitt-Packard. Together, the merchant suppliers and the captive suppliers produce products which satisfy over 70 percent of the US domestic market and 35 percent of the world market.

Top-Ten Merchant Semiconductor Suppliers-1990

(worldwides sales in $M)

Rank	Company	ICs
1	NEC Corp	4145
2	Toshiba	3570
3	Hitachi	3205
4	Intel	2915
5	Motorola	2750
6	Fujitsu	2765
7	Texas Instruments	2715
8	Mitsubishi	2035
9	Matsushita	1285
10	Phillips	1175

Source: Integrated Circuit Engineering

Figure 13.

Decline in Semiconductor Competitiveness: Is it real?

Many industry and government organizations have written emotional treatises on the decline of the US semiconductor industry. The Semiconductor Industry Association and the Aerospace Industry Association have lobbied for government policies to stem the decline in worldwide US market share. The US no longer is the world's largest consumer of semiconductors. Japan's market is the now the largest, driven by growth in: computers, consumer/automotive electronics, and telecommunications. These trade associations assume that a nation can maintain its comparative advantage forever. Lessons of history tell a different story.[24] In the dynamic world of international competition and interdependence, comparative advantage will shift with technology diffusion. The US domination of semiconductors in the 60s and early 70s was a serendipitous event.

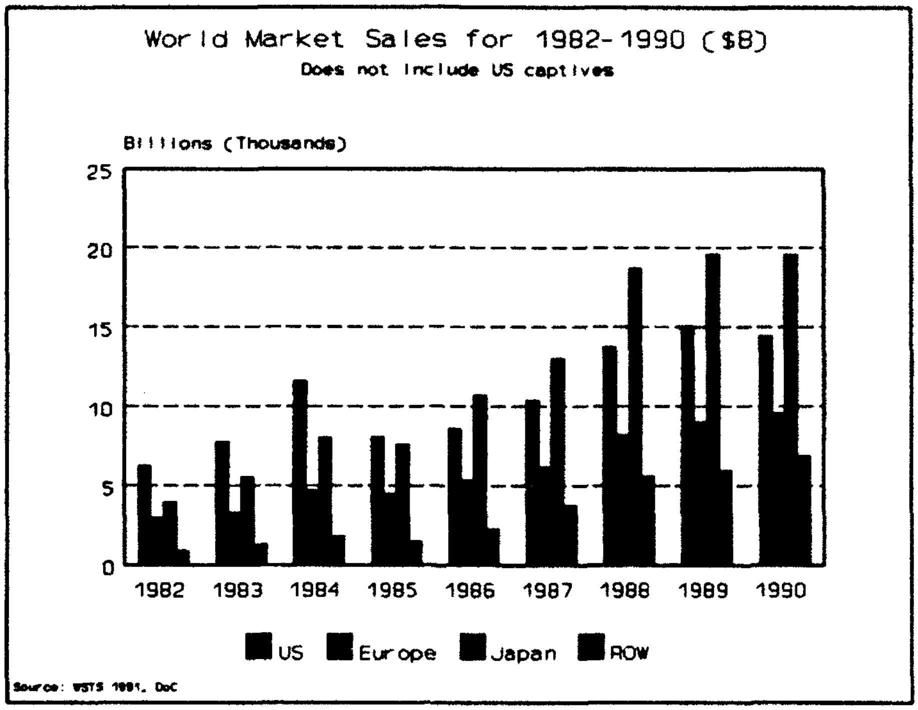


Figure 14.

The large US domestic market and the US defense purchases, coupled with the World War II destruction of Japanese and European industries enabled US firms to dominate production without any competitive pressures. International competition has replaced defense purchases as the catalyst for innovation and competitiveness. US firms have responded. They have slowed the loss of world market share, and they still produce over 70 percent of the US domestic consumption--a sign of some inherent strength in the US market.

Semiconductor Demand Trends

The demand for semiconductors is basically a derived demand and the composition of this demand is changing. Figure 15 shows the major industries and their expected influence on the semiconductor industry.[25] Defense purchases of aircraft, battle management systems, missiles, telecommunications, computers, and ships indirectly influence semiconductor demand. The decline in the defense procurement account in the 1990s will lessen government's influence over this industry. The Electronics Industry Association estimates that defense purchases indirectly account for 25 percent of US semiconductor production, and Dataquest Inc. estimates that defense purchases account for only 4 percent of worldwide production. These percentages are expected to decline throughout the 1990s, even thought semiconductor will be increasingly used in defense systems.

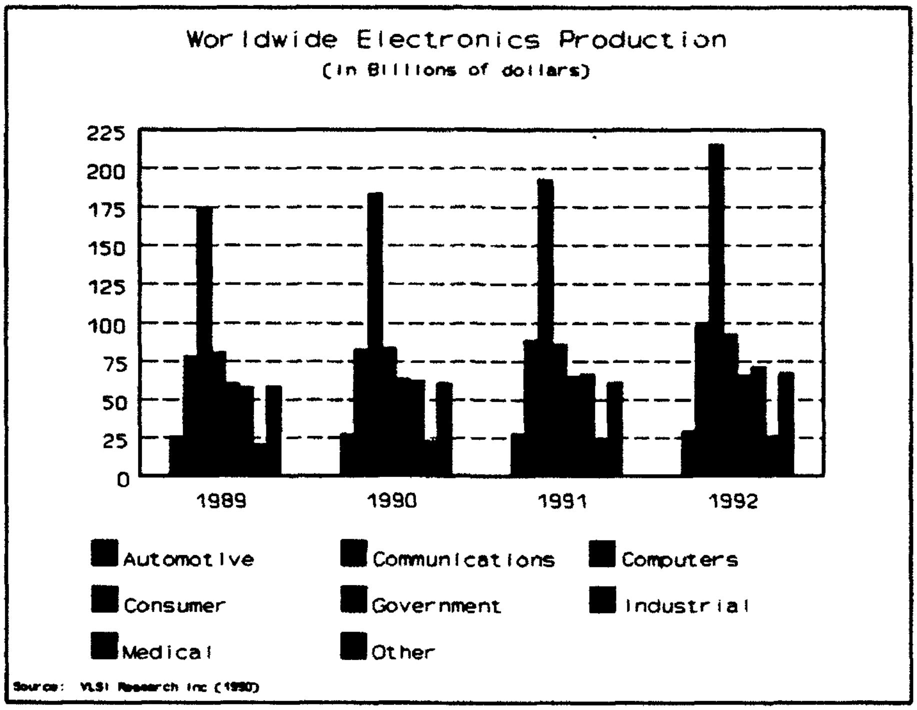


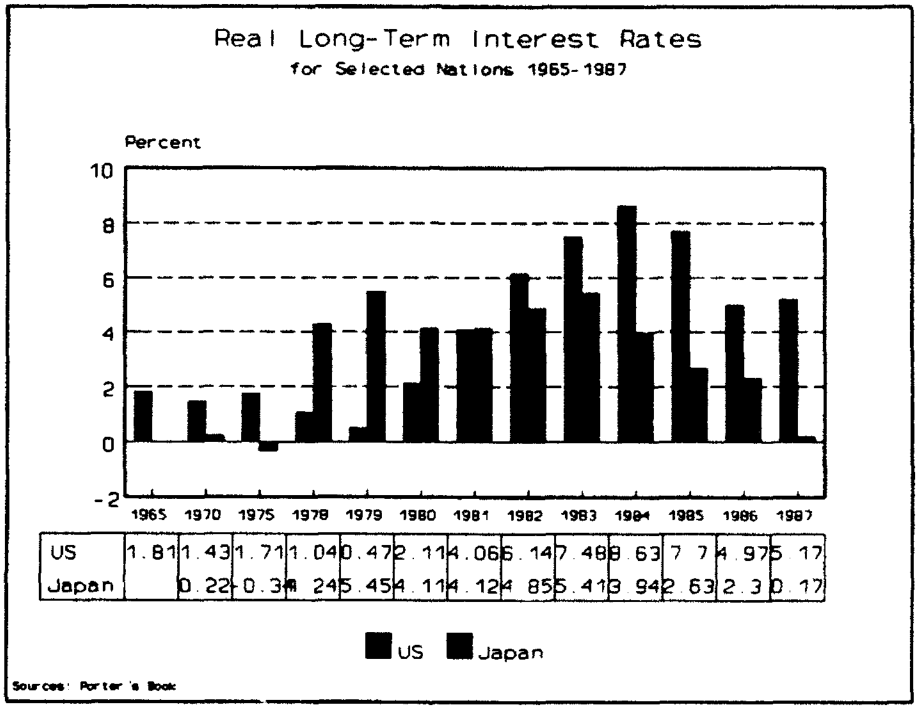
Figure 15.

Medical, computers, and automotive industries will become the dominant US consumers of semiconductor products. Collectively they will determine the overall profitability of this industry. The changing composition of US demand for semiconductors will shift from defense demand for high performance to consumer demand for lower costs. This will force manufactures to capitalize on technological improvements to lower cost for downstream industries.

Two likely scenarios are: merchant firms will consolidate--driven by high capital and Research and Development costs; and/or merchant firms will move into downstream industries, such as computers and telecommunications, to improve profitability and competitiveness. Efficiencies and economies of scale, not performance, will drive a major shakeout of SEMI firms. Dataquest estimates that the 135 US SEMI firms will be reduced to 5 fabrication plants by 2001.

US Infrastructure and Policies Hamper US Competitiveness

The general US economic environment has greatly influenced the behavior of domestic semiconductor firms. High inflation and interest rates in the early 1970s drove US firms to establish foreign subsidiaries for labor intensive functions such as, testing and assembly.[26] Again, in the early 1980s, high interest rates discouraged investment in capital plant and equipment necessary to produce a new generation of memory chips--the 256K DRAM (Dynamic Random Access Memory).



	1965	1970	1975	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
US	1.81	1.43	1.71	1.04	0.47	2.11	4.06	6.14	7.48	8.63	7.7	4.97	5.17
Japan		0.22	-0.34	4.24	5.45	4.11	4.12	4.85	5.41	3.94	2.63	2.3	0.17

Figure 16.

Tax credits and depreciation schedules are two fiscal instruments that have limited firms in their efforts to respond in the rapidly changing semiconductor market. The short life span of technology in the semiconductor industry requires firms to invest heavily in R&D and capital equipment. This industry spends more on R&D, as a percentage of sales, (average of 11 percent) than any other US industry. In addition, firms must make major capital purchases every three to four years to maintain a state-of-the-art manufacturing capability.

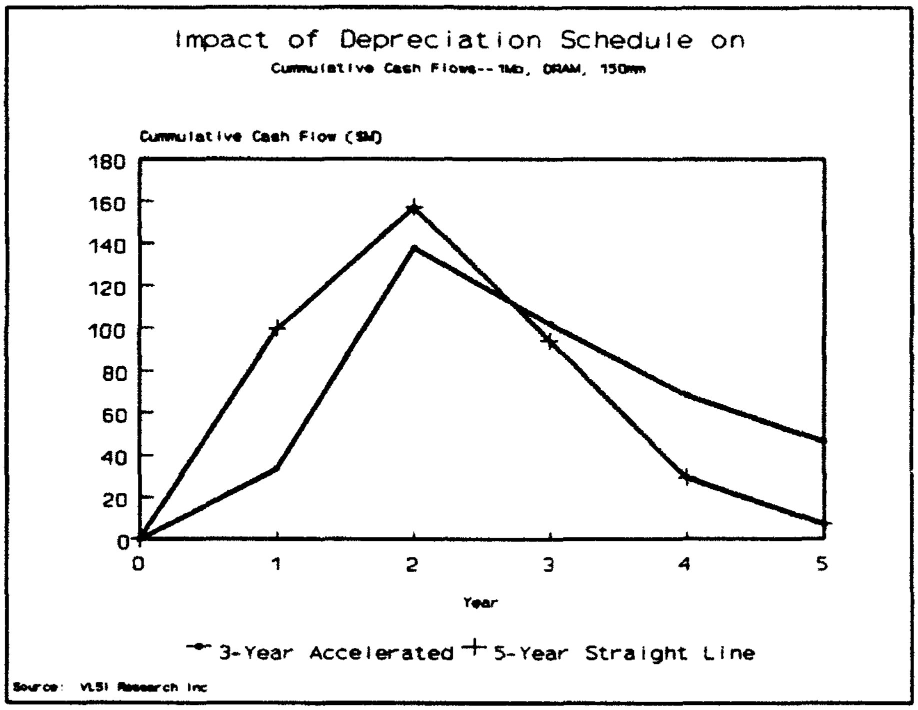


Figure 17.

Figure 17 shows the increasing costs for new plants and equipment. By the mid-1990s the cost of a semiconductor manufacturing facility will cost over $1.2 billion. Assuming the US firms spend about 20 percent annually on capital investments, then US firms would have to earn over $5 billion on sales annually to maintain state-of-the-art facilities. Few US merchant firms have been able to generate this sales volume. A recent Dataquest report comparing the depreciation schedules between a 3-year and 5-year write-off illustrates that US firm's profitability is reduced by upward of 60 percent compared to Japanese firms using an accelerated depreciation schedule.[27]

Current US Semiconductor Structure is a Source of Weakness

During the early development of the US industry the mobility of engineers and the pace of product innovation resulted in a fragmented industry structure of many small merchant suppliers. Also, the relatively low cost of capital equipment enabled firms to specialize in a given technology. Today's high R&D and production costs demand greater economies of scale. Much of the Japanese advantage in semiconductors can be attributed to their large vertically-integrated electronics firms.

In addition, the technology evolution from discrete components towards higher levels of integration places a premium on close coordination between semiconductor suppliers and down-stream industries. This does not happen in the US. US anti-trust laws are placing US merchant suppliers at a disadvantage. On the other hand, the Japanese structure of vertically integrated firms enables them to "...operate under coordinated, long-term, and integrated strategies."[28] This gives them tremendous competitive advantages.

Occupational Shifts Create a Shortage of Engineers

Finally, Ward's Business Directory which synthesizes many Department of Labor statistics highlights some fundamental shifts in the electronics industry. During the 80s, employment in the semiconductor industry grew modestly (see figure 19). By the year 2000 many of the lower skilled assembly and testing occupations will be replaced with automation. New opportunities will be created in higher skilled positions, such as engineering technicians. But, by far the greatest increase is expected in engineers (see figure 18).

Occupational Changes forecasted for 2000

base on industry group (SIC 367)

Occupation	Percent of total 1986	Percent change 2000
Electrical & Electronic Assemblers	10.8	-49.9
Electrical & Electronic Engineers	4 8	52 7
Electrical/electronic Technicians	4 0	46 3
Managers & administrators	3.5	30.4
Electronic semiconductor processors	4.0	-50 8
Engineering technicians	1 8	36.9
Sales & related workers	1.8	12
Machinists	1.2	6.1
Production planning clerks	1.4	17.9
Clerical, admin support	1.0	6.1
Blue collar worker supervisors	3.6	9.0

Source: Ward's Business Directory

Figure 18.

Yet, the supply of US engineers and scientists engaged in R&D has not changed significantly over the past 20 years. The National Science Foundation's Science and Technology: Data Book estimates that the number of engineers and scientists engaged in R&D per

10,000 of US labor force grew from 68 in 1969 to 75 in 1987.

During this same period Japan more than doubled its rate from 31 in 1969 to 69 in 1987. Viewed from a global perspective the US proportion of world's supply of engineers compared to other leading industrialized nations shrank from 66 percent in 1965 to 54 percent in 1987[29].

In addition, the supply of engineers and scientists with advanced degrees has only remained constant due to the increase of foreign students--now 45 percent of all advanced degreed students. This general decline in the supply of engineers and scientists will create keen competition and can lead to increased labor costs in the future for the semiconductor firms.

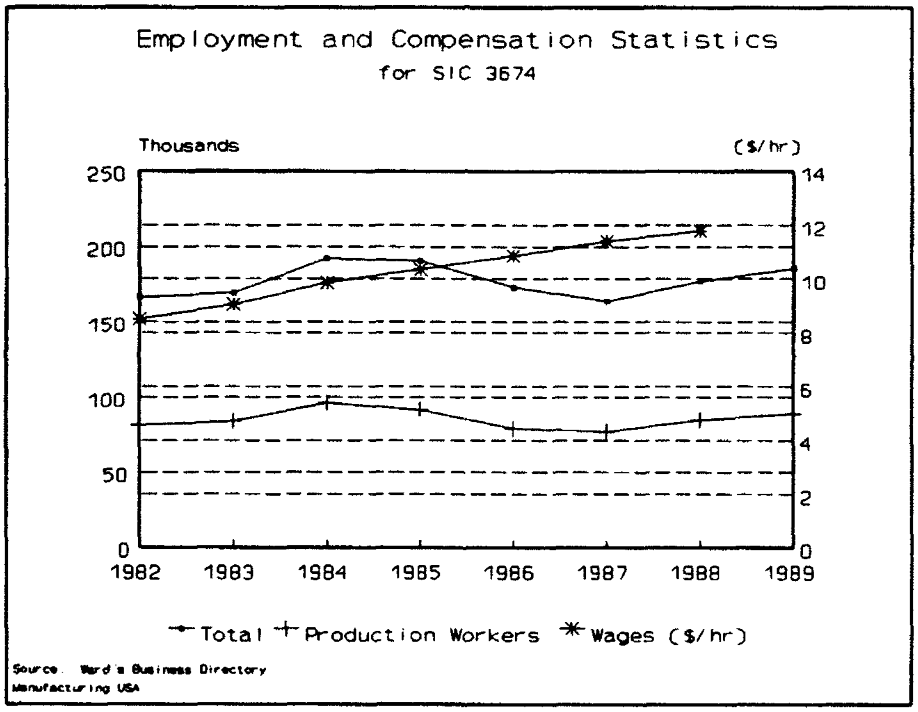


Figure 19.

Chapter 4

Conduct of selected firms in the semiconductor industry

The conduct of the semiconductor firms is shaped by the firms' management styles and the barriers to entry. This chapter will examine these issues, through the eyes of selected firms, in an attempt to understand the factors which influence a firm's business strategy.

Management Strategies of Selected Firms

Semiconductor firms are very diverse. They vary in size from small firms with annual sales of under a half-million to large multi-billion firms. They follow different strategies; many focus on niche markets, while others provide a broad array of products. Therefore, general statements about the conduct of firms may be specious. Instead, a cross-section extracted from the latest S&P Industry Survey and Dataquest's Semiconductor Industry Survey can provide examples of management strategies used by firms in competing with one another. These include:

Intel Corporation is a leading manufacturer of microprocessors. Its designs of logic chips, including the very popular 80386 chip, are widely used in personal computers. These chips have made Intel one of the most profitable companies. Intel's success has spawned increased competition as firms try to copy versions of Intel's proprietary designs. In the past, Intel licensed second sources to provide adequate supplies of its products, but no longer. Today, Intel is more circumspect with its designs. It actively prosecutes any firm that it believes has violated its intellectual property rights. Several suits are now pending.

To diversify its product line, Intel has restructured, and now stresses a more "systems approach" designed to make it more responsive to customers. In an interview for Electronic News, Andrew Grove, Intel's chief executive officer, stated that Intel is "...giving more weight to our relations with the software community, and the imaging and mathematically intensive portions of the task."[30] Such a strategy requires Intel to develop closer linkages to the computer industry, but Dr. Grove denied that Intel was becoming a computer company. Nonetheless, Intel continues to seek out business opportunities in higher, value-added products, such as personal computers.

National Semiconductor is a company in transition. National is shifting its emphasis from general purpose products, like Intel's 80386 chip, to proprietary application-specific products. Robert Ristelhueber of Electronic News described National Semiconductor's restructuring efforts to consolidate manufacturing and improve the use of existing fabrication facilities. These actions were necessary to improve National's profitability. Ristelhueber points out that this was the second restructuring within a year. In 1990 National "withdrew from fast static RAM and CMOS gate array markets,...phased out a military test and assembly plant... and sold its facility in Puyallup, Wash. to Matsushita." Ristelhueber quotes Mel Phelps, an analyst with Hambrecht & Qiust, that National's "revenue per employee is $51,000, which happens to be the lowest of 21 semiconductor companies...the next lowest is Texas Instruments, at $96,000." In a recent Dataquest feature article "Company Analysis", Gil Amelio, president and CEO of National, described his vision for National.[31] Mr. Amelio noted two market forces which influenced his decision--more competitive pricing and migration of semiconductor firms from component production into sub-system. These factors are driving National to reduce its high fabrication costs and to improve linkages with its customers as it moves into more profitable sub-systems.

Texas Instruments (TI) is an industry legend struggling to recover its past glory. TI plans to expand its proprietary product line and concentrate on graphics and digital signal processors. It is also pressing for a higher royalties on its intellectual property rights. Value Line reports that "licensing agreements have generated close to $750 million in royalty income since 1986."[32] Dataquest's "Company Analysis" feature on TI emphasized that TI is reshaping its vision to protect intellectual property (a significant revenue source), maintaining its role as a worldwide supplier (establishing a 4Mb DRAM facility in Italy), and following a process called "harmonization"--a design strategy that results in a high reuse of existing methods, procedures and equipment across its entire product line.[33] TI expects "harmonization" to reduce its process costs 20 to 30 percent. TI's roadmap will accelerate its movement into CMOS, in an effort to catch up with industry. Mass customized products are the final component of TI's business strategy. The company plans to focus on a high value-added strategy of different products built around customized logic circuits, called application specific integrated circuits (ASICs). Finally, TI will implement its global strategy through a series of alliances to share investment and technology risks and develop a closer customer relationships.

International Business Machines (IBM) is an example of one of the integrated manufacturers which produces the Intel 80386 chip for internal use. In its quest for more powerful computers, IBM's Advanced Semiconductor Technology Center has entered into a joint venture with Siemans AG to manufacture 16 Mb DRAMs.[34] IBM plans to use these chip for in-house use while Siemans plans to sell the chips on the merchant market. Dataquest summed up the most striking point about this agreement by concluding that the high cost of building submicrom state-of-the-art fabrication facilities is forcing even large, successful firms to seek partners to reduce its risk.[35] This trend is bound to continue.

Significant Barriers to the Entry of New Firms has not stopped Growth

Barriers to entry of firms to the semiconductor industry are indicators of the maturity and growth of the industry. Significant barriers exist. They are: high R&D costs, excess worldwide production capacity, high investment costs, fluctuating demand, steep learning curves, complex technology, and a greater willingness of firms to seek legal means to protect intellectual property rights.

The late 70s and early 80s, a period of increased awareness of foreign competition, saw a boom in semiconductor start-ups. Dataquest research staff has documented over "51 semiconductor manufacturing start-ups" between 1977 and 1983.[36] Most of these new firms were established in Silicon Valley and a large percentage (42 percentage) were custom and semi-custom companies. Quite a few companies specialized in new technologies (ASICs) such as, gate arrays, wafer scale integration and gallium arsenide.[37]

Dataquest concluded that "a major reason for the upswing in start-up activity is the rapid growth in venture capital financing."[38] As shown in figure 20, that flow of venture capital grew dramatically with the 1978 revision of the capital gains tax law, "... which lowered the corporate rate from 30 percent to 20 percent and the individual rate from 50 percent to 20 percent."[39] This is an example of how government fiscal and monetary policy can become a positive stimulus to overcome barriers to entry of new firms.

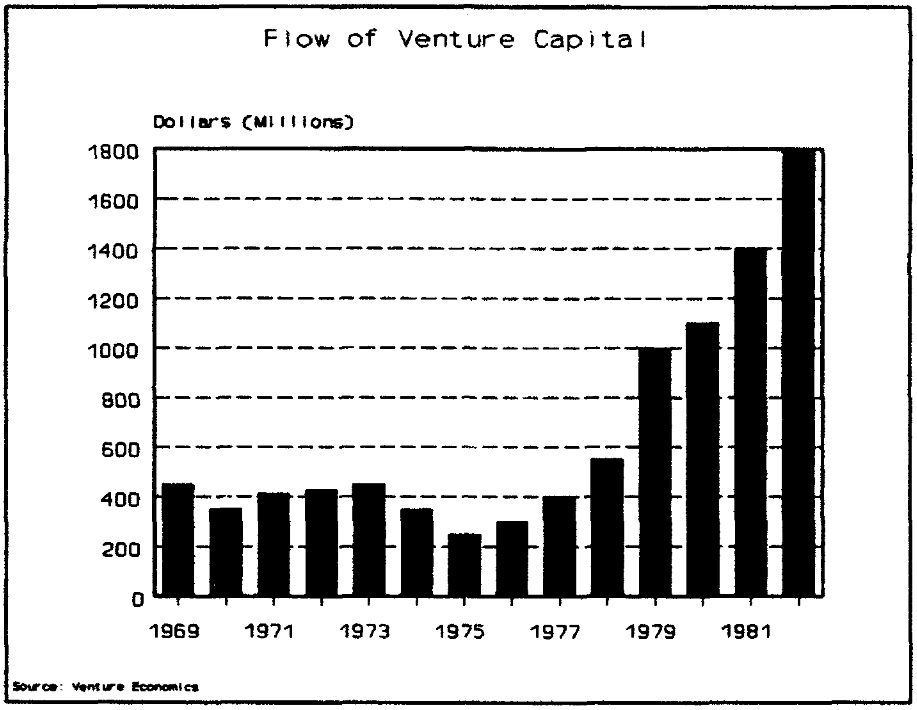


Figure 20.

Clearly fiscal and monetary policies have had a significant impact on the semiconductor industry, but there is another major reason new firms are finding it difficult to enter the industry. These factors alone are no longer the prime determinate for the entry of new firms. In the early 1980s the start-up costs for a new firm was about $250 million (see figure 21). Today it is over $1 billion for a 16Mb facility; the cost for that facility is about $332M, while the equipment costs exceed $700M.[40] This cost growth is closely tied to the approach of today's technologies to the fundamental limits of physics. As the challenges for performance and size become greater so do the costs. Unfortunately, venture capitalists can find greater opportunities for investment without the high risks in semiconductors.

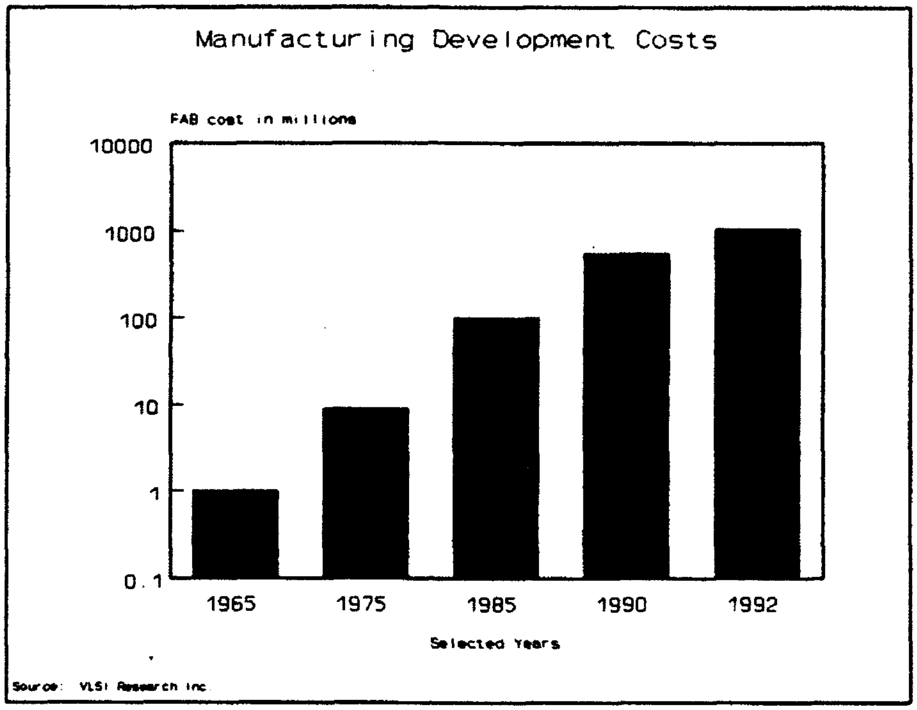

Manufacturing Development Costs
FAB cost in millions
10000
1000
100
10
1
0.1
1965
1975
1985
1990
1992
Selected Years
Source: VLSI Research Inc.

Figure 21.

Chapter 5

Government's Influence has Shaped the Conduct of Firms

This chapter will look at the government's influence on the semiconductor industry. Past government actions will be reviewed as well as two recent attempts by the government to improve the competitiveness of the industry--namely, SEMATECH and the National Advisory Commission on Semiconductors. The chapter concludes with an assessment of defense electronics concerns.

Past Government Actions

The oligopoly structure of the semiconductor industry places a great premium on price leadership. The short life cycles of technology demands that firms recover R&D cost quickly. This emphasis on rapid recovery of cost runs counter to traditional government buying practices, which tend to be slow. Nevertheless, government procurement actions were critical to the evolution and development of the industry. At other times, policy decisions resulted in unforseen disruptions. Some of the more significant government actions include:

- The 1950/60s US anti-trust action against AT&T and IBM to discourage market concentration had the favorable side-effect of changing the behavior of these firms. Specifically, these actions encouraged AT&T's research arm, Bell Labs to freely license its semiconductor designs.
- NASA requirements drove government demands for performance and reliability. This demand sustained the industry during its early growth period. At times the US government consumed over 90 percent of all IC production. Without government consumption, the high costs would have discouraged innovation.
- Trade restrictions destroyed the domestic dynamic random access memory (DRAM) market in 1986. US actions to stop illegal dumping of Japanese memory chips established a minimum selling price for imported memory chips--DRAMs. Unforseen US demand and a lack of US industrial capacity caused the US market share to shift to Japan along with enormous profits. Today only three US firms remain in this market.

More recent actions involve less direct buying, but more policy issues. Two of the most noteworthy efforts are SEMATECH and

National Advisory Commission on Semiconductors (NACS). However, none of the recent efforts have achieved much real progress. SEMATECH, NACS and the several recent technology plans certainly are improving government's awareness of the semiconductor issues, but little is provided in terms of real action. The following sections will take a look at two of these management initiatives.

The Semiconductor Manufacturing Technology Initiative

The latest government intervention came in 1987 with the formation of SEMATECH--which stands for Semiconductor Manufacturing Technology. DoD is sponsoring this six-year government-industry consortium to improve US semiconductor manufacturing methods. Participating firms can avoid duplicate R&D efforts and improve their competitiveness. SEMATECH's goal is to restore US leadership and excellence in the semiconductor manufacturing process.[41]

In its most recent report to Congress, DoD gave a mixed review of the industry's health. The report noted that US merchant firms have doubled their penetration of the Japanese market, that some US firms prospered in the late 1980s by specializing in microprocessors (Intel and Motorola were cited), and that there was a noticeable slowing in the erosion of US semiconductor manufacturing and equipment suppliers. The report noted IBM's announcement of a pilot production of 16Mb DRAMs in February 1990, which confirmed the US company's lead in product and process innovation. However, SEMATECH was surprised at the Japanese announcement of a manufacturing prototype of 64Mb DRAMs using an "approach first proposed by US scientists a decade ago."[42] This points out a weakness inherent in the SEMATECH structure. Namely, the pressures to reach consensus for cooperative R&D may reduce the willingness to select alternative paths for technology innovation. The report concluded with Sematech touting its "partnering" arrangements based on Total Quality Management as a strength for improving the quality and performance of semiconductor equipment suppliers.

The National Advisory Committee on Semiconductors

The White House Office of Science and Technology Policy sponsored the National Advisory Committee on Semiconductors which recently released a report on integrated circuit manufacturing, called MICRO Tech 2000. Jack Robertson summarized this report in Electronic News citing a "worldwide consolidation of the semiconductor industry over this decade...."[43] The report forecasts turn-of-the-century chips manufactured with 0.12 micron (one millionth of a meter) linewidths, microprocessors performing at 400MHz clock speed (today's speeds range from 33 to 50 MHz) and 4-gigabit DRAMs (as opposed to state-of-the-art 16 Mb DRAMs).

The report based its consolidation forecast on the increasing costs for capital equipment and R&D--estimated in the multi-billion dollar range by 2000. The huge financial risks will require a joint government-industry-academic program with international partners. The report also cited concerns about disjointed efforts to advanced semiconductor technology that exist in federal laboratories and agencies, universities and in industry. Some other challenges referred to in the report are:

- Need for a new generation of test equipment to measure 0.12 micron geometries.

- Ultra-clean rooms with particle levels down to 1 particle per cubic foot.

- New generation of lithographic systems to print line widths as low as 0.12 microns.[44]

The Office of Science and Technology Policy has asked the Semiconductor Industry Association, a trade association, to take the lead in putting the Micro Tech 2000 recommendations into action. It's important to note that the report is advisory and the respective actors--government, academia and industry are not bound to implement these recommendations.

Defense Purchases Stimulate Innovation

Defense products have traditionally pushed technological frontiers in performance and reliability. In doing so, defense had to spend more for a product than commercial or industrial consumers would be willing to pay. In the case of semiconductors, as production lines stabilized and learning curves improved, the product costs fell dramatically. This advantage was passed on to the American consumer in the form of inexpensive products, like radios and home computers. Thus, defense demand enabled the development of new products, which industry would not have been willing to underwrite.

Tilton noted the importance of the defense market for new firms--"...[new] firms often have started by introducing new products and concentrating in new semiconductor fields where the military has usually provided the major or only market. Fortunately for them, the armed forces have not hesitated to buy from new and untried firms."[45] This strategy is changing as military budgets shrink.

Defense Electronics Firms are Concerned

The Electronic Industries Association (EIA) <u>Ten-Year Forecast of</u>

Defense Needs (1991-2000) confirms the slowdown of military demand and "a trend toward commercial off-the-shelf and non-development items and a trend away from military specifications...." Military electronics represent about 4 percent of worldwide semiconductor consumption. This percentage is unlikely to grow even though more modern military equipment requires an increasing use of semiconductors.

The decline in DoD's budget for research, development, test, and evaluation (RDT&E) in 1994 is setting off alarms in the defense electronic industries. Geoffrey K. Bentley, business research manager for Textron Defense Systems, was quoted by Peter Burrows of Electronic Business as saying "the number of companies participating in military R&D is shrinking and threatens to erode the nations's technology edge".[46] C.M. Herzfeld, past director of research and engineering at DoD, echoed similar concerns saying "Industry can no longer subsidize R&D on projects that may never get built." These are valid concerns with no simple answers. Past strategies employed by some in industry have been to buy-in on huge R&D efforts gambling that they will win a follow-on procurement to recover costs. With shrinking procurement accounts this strategy looks too risky.

Some Positive Signs for Defense Electronics Firms

The EIA forecast does suggest that there are some big government contracts in the works. Specific programs of note are: Command, Control Communications and Intelligence Systems, Advanced Tactical Fighter, Strategic Defense Initiative, Product Improvement Programs and Anti-Submarine Warfare. Standard & Poor's Industry Survey points out that "...these programs and others require huge amounts of electronics..."[47]

A recent Dataquest Newsletter on military semiconductor demand predicts that semiconductors consumed by the electronics sector will grow 4.6 percent.[48] Not only new weapons systems, such as the Advanced Tactical Fighter, but also electronics upgrades to existing weapons (aircraft, ships, tanks, missiles) will fuel this growth (see figure 22).

Estimated Worldwide Military Consumption

(Millions of Dollars)

Types of Semiconductors	1988	1989	1990	1991	1992	1993	Growth Rate (%)
Total	2268	2285	2348	2425	2541	2691	4
IC*	1778	1827	1889	1957	2059	2192	5
Digital Bipolar	481	462	438	402	369	340	-7
Memory	83	76	67	69	52	47	-10
Logic	398	387	371	343	317	293	-6
Digital MOS	838	922	1006	1100	1214	1345	10
Memory	318	368	392	427	469	519	10
Microcomponent	196	210	227	249	276	306	10
Logic	326	365	387	424	468	519	10
Analog	460	444	445	455	476	507	4
Discrete	395	376	379	386	395	408	2
Optoelectronic	86	80	80	82	87	93	4

Source Ddtaquest (1990)

Figure 22.

Future military demand will still push the performance limits of state-of-the-art semiconductor components, but not exclusively. Instead the military consumption will follow general market trends towards more low cost CMOS and high performance Gallium Arsenide (GaAs) materials and customized products in the ASIC family. Department of Defense (DoD) and Department of Commerce (DoC) both recognize the importance of semiconductors and have included the need for research in these areas in their respective critical technology plans.

Not Everyone Agrees

Robert S. Dudney, executive editor of <u>Air Force Magazine</u>, cautions that "[n]owhere is the general US decline more evident that in the industrial sector that produces semiconductor material and equipment." Dudney goes on to cite a publication of National Advisory Committee on Semiconductors, in which the committee stated "The Semiconductor industry is at risk" because Japan is now producing the highest-quality, most-efficient chip-making equipment.

Yet, are these gloom and doom statements valid? After reading Julie Pitta's interview with James Morgan, CEO Applied Materials Incorporated (AMI), in <u>Forbes</u>, you may not agree. Morgan's firm makes super-sophisticated machines that make chips. AMI successfully penetrated the Japanese chipmaking business. The firm had to work hard to learn the Japanese business practices, but it has paid off. The firm is profitable and sells one-third of its chips in Japan. Pitta quotes Morgan's message to US industry: "Before running to Uncle Sam for help, make sure that the solution to a problem is not right in your own backyard." She interprets his view as a caution not to use perceived Japanese advantages as an excuse for poor US management.

Chapter 7

Evaluating the industry using Michael Porter's Model

Michael Porter's recent book Competitive Advantage of Nations describes four factors for improving the competitiveness of industries. This model (see Figure 23) is also a convenient framework for assessing the interactions among the different segments of the semiconductor industry.

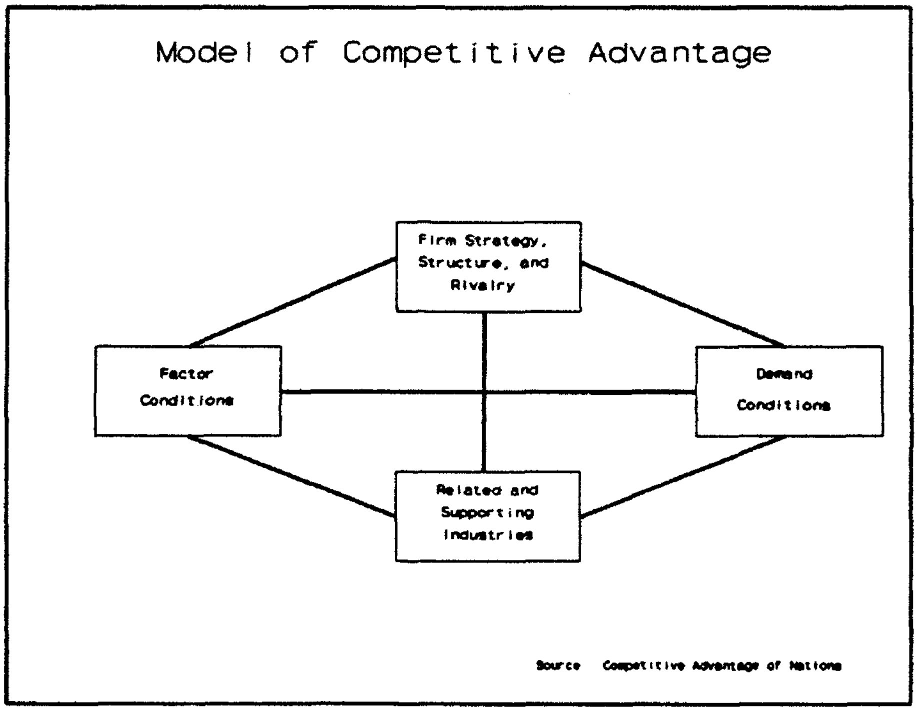


Figure 23.

Porter's theme is that competitive advantage--gauged by sustained pre-eminence in global markets--depends on persistent upgrading and innovation to enhance industrial productivity and a willingness to adapt in a rapidly changing environment. Therefore, success depends upon:

1. keen competition among firms,
2. demanding customers--such as defense,
3. a Total Quality Management competitive environment linking suppliers and downstream industries and,
4. well developed infrastructure including a well-trained

and highly-skilled workforce.[49]

All of these characteristics have been observed at one time or another in the semiconductor industry. The network model is instructive because it's a reminder that there are no simple one-dimensional solutions. Instead policy options to improve the competitiveness of the semiconductor industry must examine the interrelationships of these four factors and create an environment of cooperation at the industry level while maintaining competition at the firm level. Teamwork is required by all players--government, industry, and workers to achieve a competitive advantage.

Keen Competition

The semiconductor industry exhibits many of the features in Porter's model. First, the competitive oligopoly structure creates keen competition among firms. The history of the industry is one of shifting market dominance as firms rose and fell based on their ability to adopt to changing technology.

Demanding Customers

Second, many demanding customers have pushed the industry to innovate. In the 50s and 60s defense needs dominated demand and pushed firms to achieve major gains in performance, reliability, and size. Today's demand is a patch work quilt of requirements from a variety of industries.

Coordination with Firms in Related Industries

Third, the linkages among firms vary from a tight integration as exhibited by captive firms to a more loose interaction among merchant suppliers. Another factor to consider are the effects of a shift from open licenses for technology to a more restrictive proprietary environment. This results in barriers to communication and slows the diffusion of technology to downstream industries. In addition, the loss of a single, dominant demand (defense) means that firms no longer perceive a clear cut strategic direction. This does not imply that defense needs should drive the industry, but only that some mechanism is required to fill this void. Some have suggested that an industrial policy can provide this direction. It depends. Government should promote efforts aimed at encouraging firms to establish closer linkages with suppliers and related industries to help the market understand customer needs.

Infrastructure

Finally, the fourth successful attribute of Porter's model is the macro economic forces that effect the behavior of all industries. Two points are noteworthy. US tax policies and monetary policy inhibit firms from taking risks. Past policies developed at the national level failed to account for industry peculiar needs. For example, the Japanese firms enjoy a strategic advantage because their tax laws allow faster depreciation rates. In a fast paced industry firms need to depreciate equipment purchases within 2 to 3 years to maintain their profitability. Also, the real interest rates in Japan are lower, thus adding to their comparative advantage.

Another macro attribute to consider is the supply of scientists and engineers (S&E) performing R&D. The US percentage of the world's supply is shrinking. In 1965 Japan's pool of S&E engaged in R&D was one-fourth of the US; by 1989 it was about one-half.[50] The US needs S&E to design, develop, and manufacture world class semiconductors. Over the last twenty years, worldwide competition has increased, but the large US domestic market masked the need for more S&E. In time, market forces will bid up the salary of S&E, to expand our supply but it may take a generation. Incentives are needed to overcome the imperfections of the market, which have allowed the supply to lag demand. People are the ultimate productivity multiplier. Adequate supplies are needed for US industries in general and semiconductors in particular to excel.

In conclusion, the US market mechanisms are too sluggish to quickly respond to the nations needs in high tech industries. Some form of government role is necessary to more effectively coordinate supply and demand needs. This role cannot be limited to the semiconductor industry. The problems are too complex and interrelated. Government policy prescriptions need to recognize the interplay of all the components of Porter's model. Otherwise, today's proposed solution will become tomorrow's problem.

Chapter 8

Performance of Semiconductor Firms

The performance of the semiconductor industry will be assessed in terms of the fluctuating demand, profitability ratios, productivity measures, research and development spending and capital investment strategies. These measures will be compared against industry norms, both domestically and foreign. R&D spending patterns for both large and medium-sized semiconductor firms will also be assessed.

Fluctuating Demand

The profitability of the semiconductor industry is cyclic. This behavior is as much a result of the structure of the industry as a result of the short life span of semiconductor technology. The merchant firms are a unique American structure. These firms are usually small and specialized producers. This size and specialization limits their ability to respond to rapid changes in consumer's buying habits. Figure 24 shows the variability in

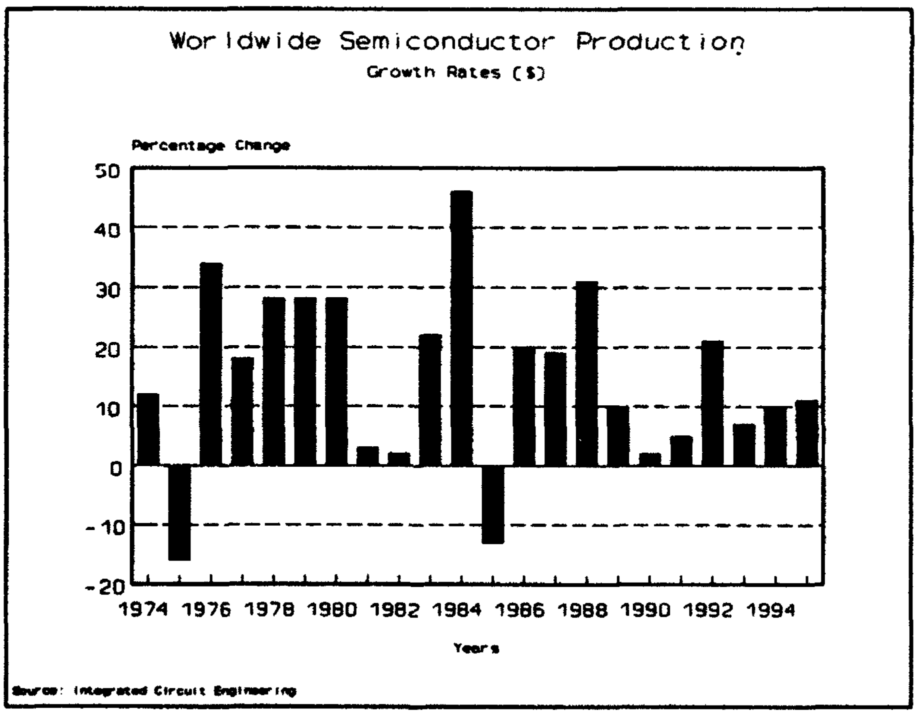


Figure 24.

growth rates for a twenty-year period.[51] Large integrated firms can more easily adjust to these changing demand patterns than the smaller specialized US merchant suppliers. Its unlikely that better forecasting can overcome this inherent demand pattern. Therefore, a change in the industry's structure may be necessary to smooth out the downturns in demand and profitability.

Profitability Measures

The overall health of the semiconductor industry measured in terms of profitability can serve to gauge how well US firms are responding to competitive challenges. The return on equity is a good basis for comparison for this assessment.[52] Figure 25 shows Standard and Poor's data for selected years in the 1980s for a sample of leading US merchant semiconductor firms.

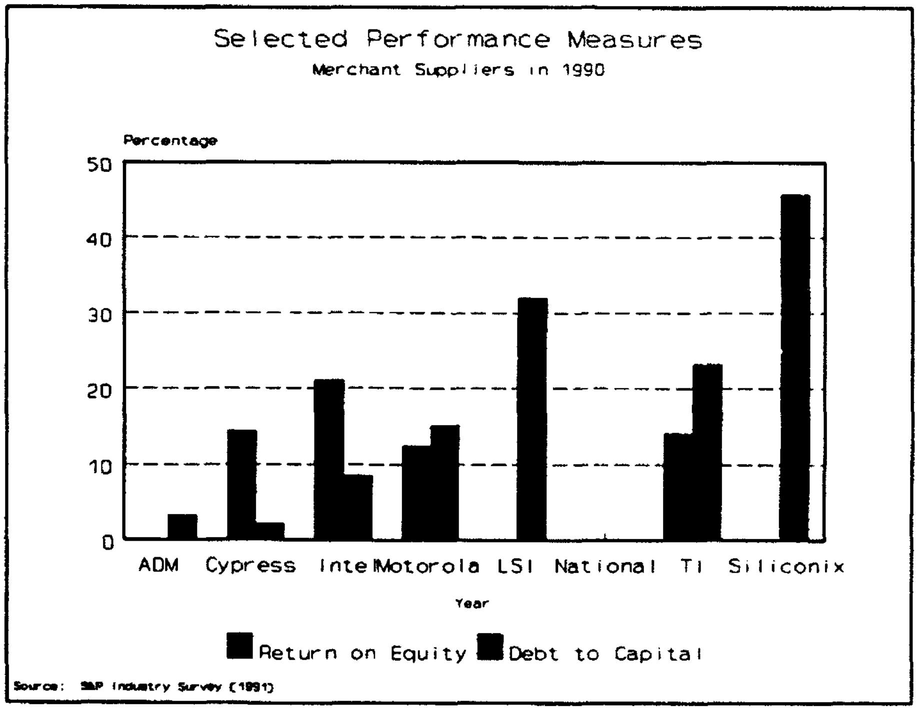


Figure 25.

These firms represent a cross-section of total US semiconductor production based on Dataquest statistics of December 1991. Measured against the Semiconductor industry average return on equity of 7.6 percent, the leading firms--Intel and Motorola--have performed well, while the smaller firms--ADM, Cypress, LSI and Siliconix--have struggled. National Semiconductor deserves a special note. National is restructuring to move into a more specialized market and it will be several years before it returns to its past glory.

Dun & Bradstreet Information Services maintains profitability measures of the semiconductor industry. Figure 26 illustrates three business ratios for profitability in 1990.[53] The median return of net worth was only 10.8. This is just below the median 12-month return for all US industry. Steve Kichen's article, "Annual Report on American Industry" in Forbes, reveals that the 1990 industry figure was 12.1 percent. This generally low return hampers the industry's efforts to obtain money to finance capital investments.[54]

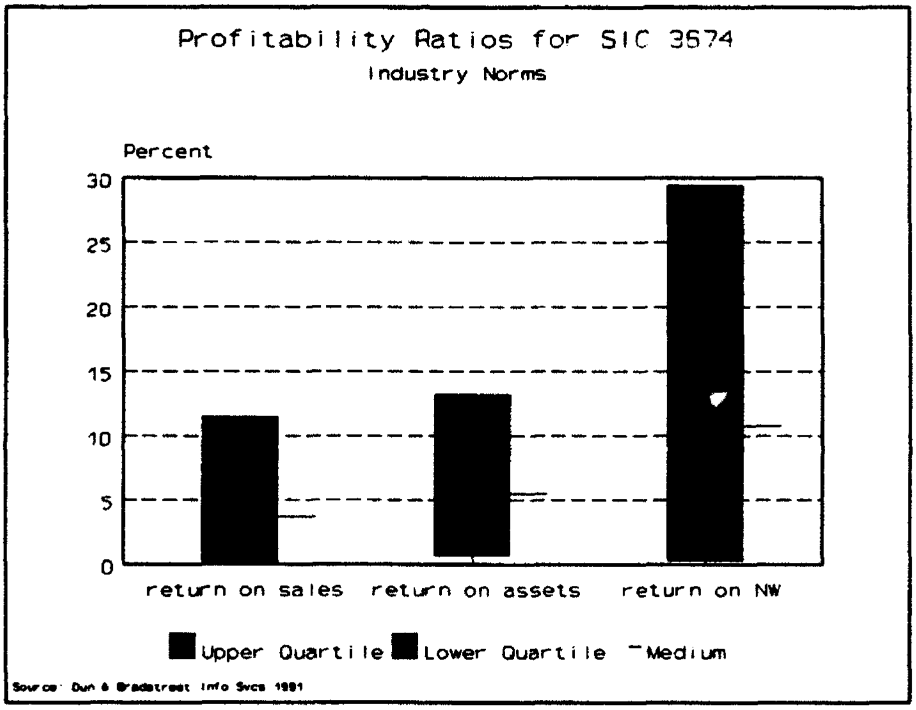


Figure 26.

Ward's Business Directory, Manufacturing USA, provides useful indexes to compare the performance of selected industries, by SIC, to the average of all US manufacturing. In figure 27 selected ratios for the semiconductor industry show the importance of investment in this industry relative to all manufacturing. This makes the semiconductor industry very sensitive to changing fiscal and monetary policies. Another noteworthy statistic is high value-added of this industry--almost four times the national average.

Selected Ratios for SIC 3674

Relative to Average of All Manufacturing

Selected Ratios	Semiconductors	Index
Per Establishment		
Payroll	$6.2 (M)	415
Wages	$2.1 (M)	269
Value added	$13.6 (M)	397
Investment	$2.8 (M)	1095
Per Production Worker		
Hours worked	1,962 hrs	100
Value added	$137,764	157
Cost	$60,410	58
Investment	$28,033	433
Per Employee		
Value added	$63,105	112
Cost	$27,672	42
Investment	$12,841	309

Source: Ward's Business Directory Manufacturing USA

Figure 27.

Productivity of the Semiconductor Industry

The MIT Commission on Industrial Productivity reports that "...US semiconductor industry has been exemplary in comparison to most other US industries" (5). As figure 28 shows, total factor productivity exceed 10 percent throughout the 60s and 70s--a period of preeminence for the US semiconductor industry. The industry's performance in the 80s, although excellent by aggregate measures, was insufficient to overcome competition from Japan. Thus, Japan was able to gain a larger share of the world's growing demand for semiconductors.

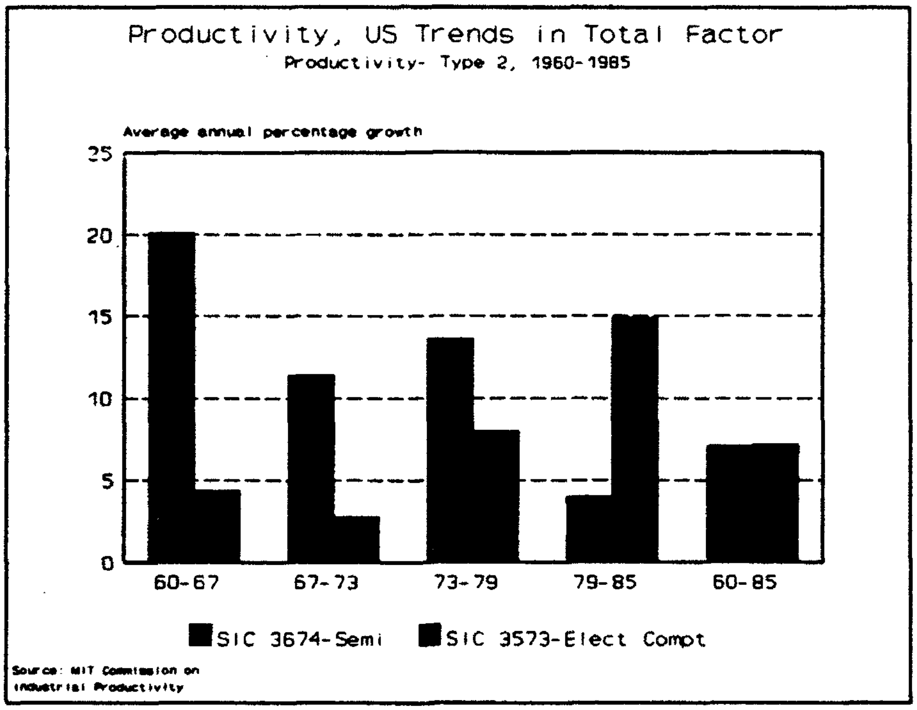


Figure 28.

Semiconductor R&D Leads Most US Industries

Semiconductor firms also posted one of the highest investment ratios of R&D to sales of the top firms in the US. Business Week estimated that for 1990 the total R&D spending as a percent of sales for the US industry as a whole was only 3.4 percent. US industries lag in R&D spending compared to the top 200 foreign firms, which spend about 4.3 percent. However, industry averages frequently mask the underlying strength of specific segments of the US industry. The semiconductor industry is a good case in point. For 1990, the semiconductor industry ranked second, after software & services, in R&D spending as a percentage of sales.

The real problem is that the top eight Japanese semiconductor firms spend in absolute numbers $14.4 billion on R&D compared to $2.4 billion spent annually by US semiconductor merchant firms.[55] These large Japanese firms have deep pockets to finance R&D innovations and can support a broad range of technology developments. However, we are comparing apples and

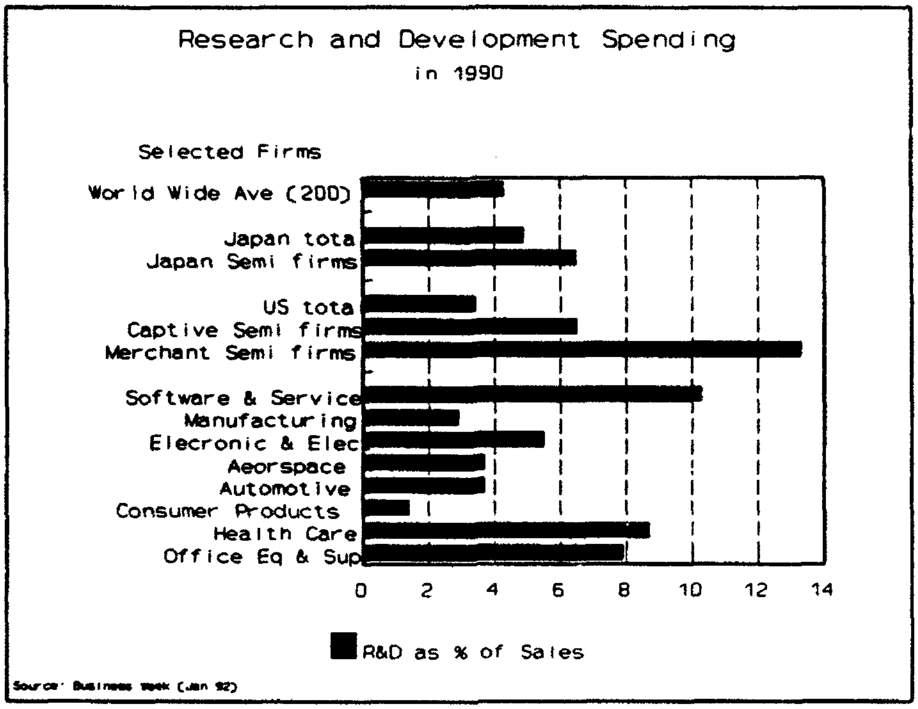


Figure 29.

oranges. The Japanese semiconductor firms are large, integrated firms and could be more accurately compared to US captives such as, AT&T and IBM. Both Japanese semiconductor firms and US captive firms spend about 6.5 percent of sales on R&D. Therefore, all things being equal, the R&D business practices of the US captive firms are compared quite favorably with their Japanese counterparts.

Medium-size Merchants use Innovative Business Strategies

Most semiconductor firms are medium-sized companies which employ a management strategy of either attacking niche markets or maintaining a strong innovative spirit to compete with the larger companies. The small size of these companies is an asset since it shortens the communication lines between development and manufacturing, thus improving the firm's ability to quickly bring new products to market. Figure 30 extracted from a Dataquest perspective on medium-sized firms (those with revenue between $200 and $500 million per year) shows that smaller firms spend more on R&D as a percentage of revenue than merchant firms in general.[56]

Comparison of Percentage of Revenue Spent on R&D
by medium-sized firms and US Merchant average

Company	($M) Revenue	R&D Spending	R&D as % of Revenue
IDT	206	44	21
Cypress	219	55	25
Chips & Technology	255	49	19
Hewlitt-Packard	279	45	16
Micron Technology	256	41	14
VLSI Technlogy	322	54	17
Analog Devices	351	73	19
Merchant Average			14

Figure 30.

Although they don't have the generous budgets of their larger competitors, the size of these firms frees them from bureaucracy and therefore enables them to quickly implement changes. This flexibility provides them with a competitive advantage.

Cypress Semiconductor entrepreneurship exploits the advantages of medium-size by funding the start-up of its own subsidiaries. These subsidiaries build their own fabrication facilities unencumbered by the parent firm and transfer the technology and new process ideas back to their parent. This approach suffers one significant shortcoming. Medium-sized companies cannot afford to subsidize many start-ups because of the high capital costs of equipment. Thus, they must concentrate on niche markets to survive. These firms tend to follow the lead of their larger competitors in investing in new equipment. Informal sources such as trade associations and market research data are frequently used to evaluate new equipment. This places medium-sized companies at a disadvantage in terms of state-of-the-art equipment, and thus their capital plants lag behind their larger competitors by one or two generations. To survive in this niche market, these firms will have to develop strategic alliances with firms in downstream industries to coordinate and integrate business strategies and share risks.[57]

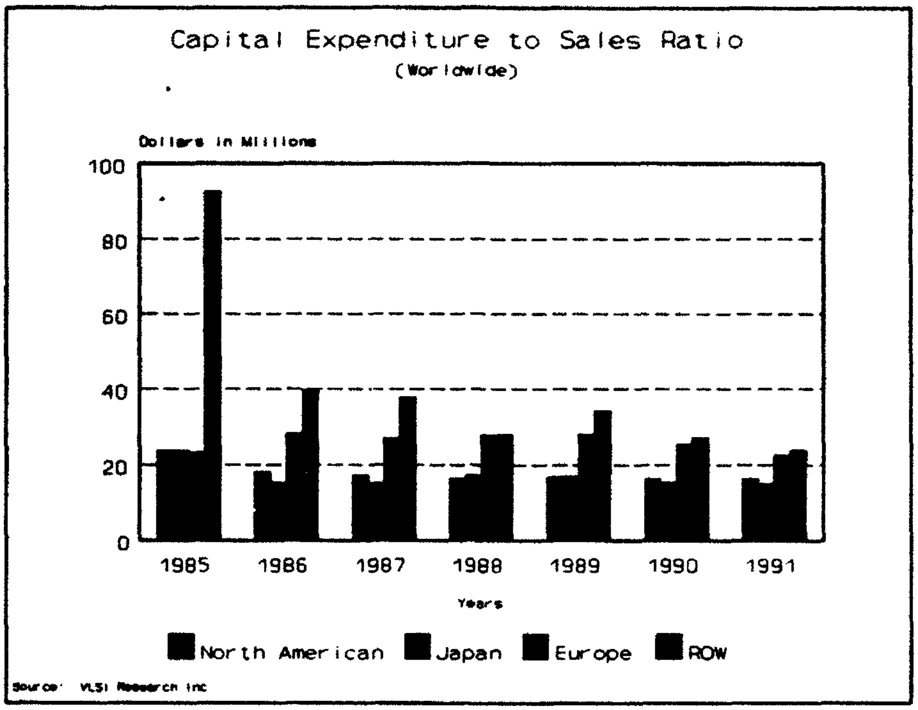


Figure 31.

Capital Investments

Capital investment is also a source of enduring strength. The facts show that capital costs are continuing to soar upwards (see figure 21). This is to be expected as firms push the frontiers of existing technology. US firms may be at a disadvantage in competing for investment capital due to high debt and high real interest rates. However, a view of the performance of US firms, measured as a percentage of sales, shows the US even with its major competitor Japan (see figure 31).[58] Both countries use much the same investment strategies, investing about 18 percent of sales for capital spending.

Dataquest has cited one strategy that VLSI Technology used to overcome high investment costs, namely "...VLSI and Hitachi have joint licensing agreements and technology exchange agreements"[59]. The article further states that under such a partnership VLSI was able to move "...from 1.0-micron process to demonstrating a .45-micron transition structure in just three years." This is not a unique arrangement. The semiconductor industry has a history of licensing agreements which have helped diffuse technology.[60]

The most recent effort to improve the competitiveness of US firms in process innovation is SEMATECH. This should have provided examples of how US merchant firms could have shared in the benefits of technology transfer of new process technology. Unfortunately, most of the smaller merchant firms could not afford the up-front cost to participate. T.J. Rodgers, President of Cypress Semiconductor, voiced his concerns about SEMATECH in Electronic News.[61] He told Congress the SEMATECH is withholding technology from "hundreds of American electronics companies--while using taxpayers' money to benefit its 14 member semiconductor firms." At issue is a practice of withholding technology for up to one year for anyone but the 14 Sematech member companies. William Spencer, Sematech president, disagrees. Mr. Spencer told the House Science, Space and Technology Competitiveness Subcommittee that equipment used in Sematech program is available "anywhere in the world the day it is introduced on the market."[62] If the US is going to remain competitive in the world semiconductor market, some means must be found to blend the strength of medium-sized firms in product innovation with the financial prowess of the larger firms in exploiting process innovations.

Chapter 9

Observations

• Research and Development costs are high in this industry. They average between 6 and 27 percent. Robert Buderi in his January article in Business Week magazine noted the semiconductor industry as one of the industries with the highest R&D cost as a percentage of sales--10.3 percent. This contrasts dramatically with the US average of only 3.5 percent.

• Demand is cyclical. High R&D costs and short life span of a generation of technology--often just 3 to 4 years, cause the rapid decline in price once a product is introduced into market. It's not uncommon for prices to be slashed in half within one year. Many consumers can afford to wait to fill their orders. Then they rush their orders through all at once.

• With each generation of technology, the cost of manufacturing increases manyfold. Today the cost of wafer production equipment is around $250 million and rises with every generation.

• Easy entry conditions into the market helped spur the diffusions of technology. AT&T's liberal licensing policy and high interfirm mobility of scientists and engineers were the two most favorable ingredients for helping to establish new firms. The readily available skills and the open licensing policy are no longer features of the industry.

• Rarely has one firm dominated the market (i.e. greater than 25 percent market share)

• US firms have in the past willingly transferred technology to foreign firms to establish de facto standards--Texas Instruments today derives a significant portion of its income from these past licensing agreements. This strategy helped provide adequate supplies, but created competition. This is changing as firms stop licensing their new designs--INTEL will not license its design for the 386 microprocessor chip.

• The growing scientific and engineering prowess of foreign countries requires the US firms to look overseas for innovative ideas. However, much foreign technical literature remains untapped because of cultural and linguistic differences.[63] The US needs to expand its understanding of foreign cultures to aggressively seek out new ideas.

• Industry is still in a rapid-growth, research-intensive stage. A mixture of merchant suppliers and captured firms has fostered both innovative products and improved processes. However, the industry structure is changing as merchant suppliers become more integrated by expanding into down-stream, higher value-added electronics markets such as computers.

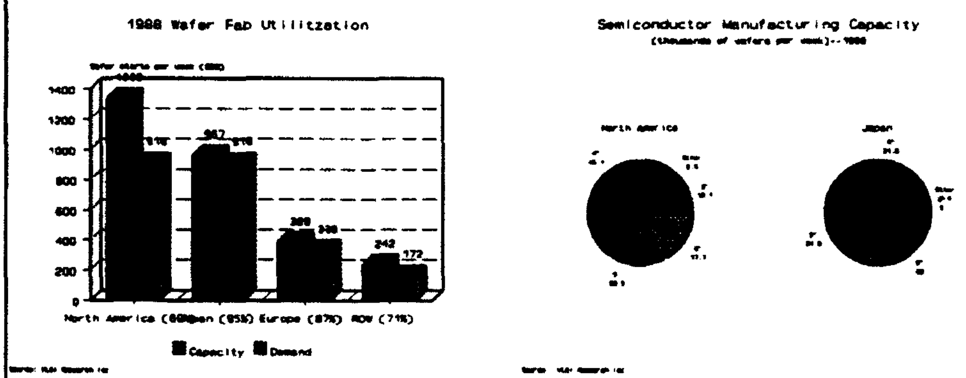


Figure 32.

• Excess capacity of the semiconductor industrial base along with an aging capital plant, limits the competitiveness of US firms. Inefficiencies characterized by a large percentage of smaller wafer sizes and low utilization rates contribute to the low profitability of US firms (see figure 32). Consolidation is inevitable, as firms reduce excess capacity and modernize production lines.

• Federal demand has been positive. The demand for semiconductors in the late 50s and 60s, for the US space program and arms buildup, helped establish clear technological targets, which enabled the US to dominate the market. However, the impact has not always been positive. DoD appears to discriminate in awarding R&D contracts to established firms. This dampens innovation. New firms need defense contracts to sell products which otherwise would be too expensive for commercial or industrial use--at least initially.

- Public policy, which was so important in the infancy of the semiconductor industry, needs to be carefully crafted to be effective. Gross generalizations applicable to all industries will not work. Malerba describes a strategy for public policy as one which stresses flexibility. He cautions that "...in industries with a high rate of technological change, such as the semiconductor industry...targets of government policy cannot always be defined with accuracy" (244). He further stresses that "...adaption and response to the changes..." are the key ingredients of good policy. Specific actions should include: encouraging investments in foreign subsidiaries to acquire know-how from innovating foreign firms, preventing restrictive patents, encouraging firms to share critical technologies, and providing incentives to improve industry production techniques.

Chapter 10

Recommendations for Action

The US semiconductor industry has exhibited some inherent strengths that have enabled US firms to remain competitive in the world market. Semiconductors remain a strategic resource for the US economy and our national security, since they provide the raw materials for continued improvements in performance, cost, and reliability of a wide variety of US manufactured products. Reductions in the defense procurement budget mean that defense will no longer be the dominate factor for continued improvement in semiconductor products. Therefore, policies are required to stimulate keen competition among the industries to ensure US innovation in manufacturing products and processes in the semiconductor industry.

• The Office of Science and Technology Policy should develop an Industrial Strategy for US industry. This strategy would focus policies on broad nonindustry-specific factors of US competitiveness. US subsidies should be avoided, except for infant industries. For example, the US should:

-- create incentives to increase the supply of US scientists and engineers,
-- encourage long-term decision-making by industry for R&D and capital investment using tax incentives and accelerated depreciation schedules,
-- relax anti-trust laws to encourage closer interaction among suppliers and firms to sharpen customer demands for new products prior to manufacturing,
-- signal governments commitment to education with incentives for students to complete high school,
-- require four years of foreign language education in high school and demonstrated fluency to for a baccalaureate degree to tap foreign ideas,
-- require Department of Commerce to coordinate with trade associations, such as Semiconductor Industry Association (SIA) to assist firms in developing strategies that would make their products more competitive in the world markets.

• Encourage US firms with tax incentives to establish non-competitive R&D institutes in collaboration with universities. For example, the Semiconductor Industry Association could establish a consortium with leading universities in electrical engineering.

- -- SIA member firms could reap synergistic benefits of technology diffusion and interchange by sending their employees for advanced education at this institute.
- -- Downstream manufacturing firms in the computer, medical, aerospace, automotive, and consumer industries would be encouraged to participate.
- -- Military and defense planners would also be encouraged to pursue advance degrees at this institute to provide insights on potential weapons capabilities.

• Encourage semiconductor firms to continue joint-ventures and consortia such as SEMATECH. Shift basis of competition of firms from product innovations to process and manufacturing prowess.

- -- Restore the collegial environment of the semiconductor industry to that of its early years (1950s/1960s) by fostering a willingness among firms to freely license innovations.

• Change the accounting rules to redirect senior management towards long-term growth and innovation.

- -- Eliminate quarterly reporting of financial data.
- -- Require productivity measures to be included in all financial reports.

• Department of Defense should establish a consortia of defense electronics firms to collaborate on advanced prototypes for defense electronics. The government would grant unlimited data rights to all participants.

- -- Redirect Department of Defense Science and Technology budget to provide $300 million in seed money.[64]
- -- Make the benefits of basic and applied research available to all US firms.
- -- Emphasize affordability verses performance trade-offs in future weapons.
- -- Eliminate all fixed-price R&D contracts and require all R&D to be performed using consortia of interested firms.

Chapter 11

Conclusions

The federal government has been a major factor in the development of this industry. Early anti-trust action changed the behavior of firms like AT&T and IBM, and, as a result, new firms were encouraged to enter this industry. Also, military demand for small, reliable, high-performance products in missiles and satellites was critical for the early development of this industry. At present, federal spending accounts for about 4 percent of world demand. This is down from about 95 percent in the 50s and 60s. Global competition is the new major factor driving the performance of this industry.

The semiconductor industry is not at risk. The loss in market share is part of the natural forces of competition. Past management complacency and a large domestic market masked the impact of foreign competition and thus led to a reduction in US dominance of semiconductors. The changes in the world market would have occurred in any case.

The transition period is not over and more consolidations are probably necessary to reduce excess capacity and improve profitability. The White House needs to accept these realities and develop an industrial strategy to restore business confidence, to increase the supply of scientists and engineers, to maintain a stable monetary policy, and to remove all regulatory policies which inhibit firms from seeking long-term business strategies.

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Index of Figures

Endnotes

1. National Advisory Commission on Semiconductors, "A National Strategy for Semiconductors" Wash DC Feb 1992 p2.

2. The "Big Eight" tube manufactures were General Electric, RCA, Sylvania which accounted for 70-80 percents of the American production along with Raytheon, Tung-Sol, Philco, CBS, and Westinghouse.

3. In "The Big Score" Malone explains how a lack of venture capital forced smaller companies to seek cash rich firms in order to upgrade their facilities and to manufacture the latest technologies. During this period Siemens bought Litronix and 20 percent of ADM. Northern Telecom took 24 percent of Intersil and later sold it to General Electric. Electronic Arrays was sold to NEC. Honeywell bought Synertek; Bosch purchased 35 percent of American Microsystems; Gould later bought all of American Microsystems; Philips already owned Signetics; Westinghouse bought Intersil; and IBM bought 12 percent of Intel.

4. Two of the more well known examples of firms that entered the gate array market are: VLSI Technology and LSI Logic. By 1983 over a half dozen gate array firms started in Silicon Valley.

5. T.R. Reid's "Personal Computing" column relates how American chipmaker Intel improved a Japanese design of flash memory and now controls about 85 percent of the market. Flash memory is highly efficient means for storing data in a computer which is expected to replace today's hard disk drives.

IBM recently announced that it was beginning production of 16MB DRAMs. In doing so, IBM has taken a leadership position in this market.

6. Moore's Law was named after the confounder of Fairchild and Intel and predicts a 30 percent drop in the price per bit each year. In lay terms this means that the price of a chip for a certain speed drops 30 percent year-in and year-out.

7. Ibid.

8. See Malerba (1985), p(15).

9. Ibid, p(206).

10. See Dataquest Inc.'s SIS Products-Markets. Mar ed. 1986. p(A-8).

11. Ibid. p14.

12. Ibid. p14.

13. Ibid.

14. See Dataquest Inc. "Final 1990 North American Semiconductor Market Share Estimate." May 1991.

15. Statistics are derived from Dataquest's Top 40 Table for the supply of total semiconductors to North America. Includes only US companies, reported in the "Final 1990 North American Semiconductor Market Share Estimate.", p(2-2).

16. See Losman, D., Liang Shu-Jan, The Promise of American Industry, NY: Quorum books, p27 for a discussion of the types of market structures.

17. See, Dataquest Inc.'s Product Analysis. "Will 4Mb DRAMs Have a Short Life?", 1991, p(13).

18. See, Department of Commerce report on the US Semiconductor Industry, Sep 1979, p(50).

19. See Dataquest Final 1990 North American Semiconductor Market Share Estimate. May 1991.

20. See article "Sooner of Later, 'Flash memory' Will Replace Hard Disk Drives", by T.R. Reid in the Washington Post (March 92). Reid claims that Intel's improvements on the Toshiba design has enabled it to garner 85 percent of the flash memory market.

21. Ibid.

22. Electronic News V37 p24(1) June 17,1991 Testifying before the House Committee on Science,Space, and Technology's Subcommittee on Technology and Competitiveness, Mr Reed stated that US chemical and materials companies don't have the investment capital they need to remain competitive.

23. DoD in its most recent SEMATECH report to Congress cited positive trends. The number of semiconductor firms who planned to buy US manufacturing equipment has increased.

24. Paul Kennedy's Decline and Fall of Great Powers provides an excellent account of this dynamic. For example, in the 1800s Britain dominated the world's supply of textiles, but today this dominance has shifted to the Pacific Rim, specifically China.

25. See VLSI Research Inc.'s "Industry Forecast", Fall 1990, p(130).

26. See DoC report on US Semiconductor Industry, p(74).

27. See VLSI Research Inc's Manufacturing Outlook article on "Depreciation Schedules: Their Impact on the International Competitiveness of Semiconductor Manufactures". This article empirically shows that regardless of national policies, the country with the shortest depreciation schedule has an advantage. Why? Because the company with a 3-year schedule will write-off its capital cost just before technology change causes prices to dramatically fall.

28. See The Working Papers of the MIT commission on Industrial Productivity, Vol 2, p(16).

29. National Science Foundation Data Book, "Scientists and Engineers engaged in research and development by country:1965-87", GPO:Wash DC. p33.

30. Robert Ristelhueber, Electronic News "Intel group revamp stresses systems approach" V37 p1(2) May 27 1991.

31. See Dataquest Inc, Company Analysis article, "National's New Leader Shares His Vision" 1991, p(11-12).

32. Value line summary of Semiconductor Industry. p(106) Nov 1, 1991.

33. Galligan, Patricia, Dataquest Company Analysis "Texas Instruments: Breaking through Design Barriers" Vol 1 No2 Sep 23 1991, p8-14.

34. See IBM Annual Report, 1990.

35. Jeff Seely Dataquest Company Analysis "IBM & Siemans Sign Agreement to Manufacture 16Mb DRAMs" Vol 1 No 11 P18-19.

36. Tatsuno Sheridan, Andrew Prophet, and Howard Boget in Dataquest's Semiconductor Industry Service" Dec 1983.

37. Ibid. p(2).

38. Ibid. p(3).

39. Ibid. p(3).

40. See the VLSI Research Inc. article "Megabit Production line Comparison", VLSI Industry Forecast Spring 1991 (sec 1.5).

41. See Jonathan Weber's article in LA Times, "Chip-Making Partnership Suffering Growing Pains", Oct 21 1991. SEMATECH's original goal was to build a world-class fabrication facility. When this proved infeasible, the consortium management turned to building better relationships among related segments of the semiconductor industry.

42. Department of Defense Sematech 1991 (A report to Congress) P(9) July 1991.

43. See Robertson's article in Electronic News, vol 37, p6(2), May 20 1991.

44. Ibid.

45. See Tilton, p91.

46. Peter Burros, Electronic Business "A Single Industry Voice gets results in chip wars" V17 p11 (1) May 6 1991.

47. See Standard & Poor's Industry Survey, May 30 1991, p(E16). This report predicts an overall lackluster growth for military electronics, however, weapon systems which have a high electronics content will sustain demand. Especially, for stealth and command and control systems.

48. Gregory Shepard Dataquest Research Newsletter "Military Semiconductor Demand Update: Slow with Pocket Opportunities" April-June 1990.

49. See Harvard Business School case 9-390-001, in Yoffie's book.

50. See National Science Foundation report, Science and Engineering Indicators 1989, 1989. Appendix table 3-16. titled "Scientists & Engineers Engaged in R&D for Selected Countries: 1965-1987." p(260).

51. See VLSI Research Inc., Commerce Dept. database file DIFRAT, 1990.

52. Return on Equity--Expressed as a percentage, this measure is calculated as net income less preferred dividend requirements, divided by average common share-holders's equity.

53. Statistics are prepared annually for selected 4-digit SICs covering a broad range of performance measures.

54. See Value Line Investment Survey. The industry's perfromance measured against a composite index shows that the relative performance of the industry has fallen dramatically. In 1987 the industry outperformed the value line composite index by almost 4:1. By 1991, it fell to 1.6:1. Also, over this time period the industry's long-term debt increased from $2.1B to over $2.8B.

55. Business Week, Jan 1992.

56. See Dataquest Perspective , on "Semiconductor Equipment, Manufacturing, and Materials", Vol 1, No 10, Sep 23, 1991. George Burns essay on "Technology Development and Meduim-Size Semiconductor Companies" provides several successful perspectives for leveraging R&D costs.

57. Ibid.

58. See VLSI Research Inc. table of "Demographics of Semiconductor Sales and Capital Expenditures", 1991, p(1.9.3.4).

59. Dataquest Perspective, "Technology Development and Medium-Size Companies": Vol 1, No 10 Sep 23 91 (9).

60. Ibid.

61. Jack Robertson, Electronic News "Cypress president claims Sematech withholds technology" V37 p(5) July 29 1991.

62. --------, Electronic News, Cypress president claims Sematech withholds technology. V37 p5(1) July 29 1991.

63. The National Academy of Engineering reports that English-language versions of Japanese documents are often available only 3-5 years after the work described in them has been done. The main bottleneck is the high cost of translating these works into English.

64. The $300M estimate is DoD's fair share R&D needed to maintain parity with Japan. This value was calculated based on several assumptions: the EIA estimate that 25% of the US semiconductor purchases come from DoD, high-technology firms spend about 6% of their annual sales on R&D, and total annual sales for semiconductors is around $20B. With high-tech firms spending 6% of $20B in total sales for R&D, the total R&D is $1.2B. DoDs purchases consume 25% of this. Therefore, DoD should contribute about 25% of total R&D ($1.2B), which is about $300M.