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Semiconductor Industry Insights: Silicon to Systems

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A Strategic Analysis Report

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Preface

The semiconductor industry, in the strictest definition, comprises companies that produce semiconductor devices for sale in the open market or for internal consumption. A report on the companies that produce the semiconductors would give a picture of the industry, but not the complete picture. The complete picture emerges when the semiconductor industry is analyzed in the context of the overall structure in which it exists. And that is an interrelated structure that relies on customers, depends on suppliers, and is subject to external pressures from governments and worldwide economic conditions.

With this interrelated industry structure in mind, *Semiconductor Industry Insights—Silicon to Systems* integrates data and concepts from several Dataquest semiconductor services with regional economic forecasts from OECD, D&B, and the US DOC. Written in executive summary style, it is intended to provide high-level, insightful analysis of the recent history and near-term future of the semiconductor industry for semiconductor users, semiconductor producers, suppliers to the semiconductor industry, investors within the industry, and interested parties who want to understand the near-term future of this industry.

Semiconductor Industry Insights—Silicon to Systems was completed in July 1990, and the forecasts and projections contained within this report are based on information from several sources published in late 1989 through July 1990, as follows:

- Source
  - *Economic Outlook* (OECD), published December 1989
  - *US Economic Forecast* (D&B), published April 1990
  - *US Economic Outlook* (DOC), published January 1990
  - *Dataquest Electronic Equipment Forecast*, published May 1990
  - *Dataquest Semiconductor Demand Forecast*, published June 1990
  - *Dataquest Semiconductor Production Forecast*, published June 1990
  - *Dataquest Semiconductor Equipment Forecast*, published June 1990

About Dataquest

Dataquest is a worldwide market research company, headquartered in San Jose, California (Silicon Valley). Dataquest employs more than 700 people worldwide and operates market research resources in Japan and other Pacific Rim locations, Europe, and the United States. As a subsidiary of The Dun & Bradstreet Corporation (D&B), Dataquest has access to major economic forecasting and business databases. In addition, through its own worldwide research resources, Dataquest has compiled the most comprehensive integrated database in the world covering the semiconductor industry and its suppliers and customers.

Dataquest's Database

The Dataquest database is created by research involving ongoing conversations with some 250 different companies worldwide, surveys, examination of public business disclosures such as annual reports from more than 200 other companies, and data made available by D&B.

This database provides the underlying data and is the basis for trend analysis and forecasting at an extraordinarily detailed level for all companies within the electronics industry. Dataquest provides 11 different client services in which the data, analysis, and forecasts are presented in detailed reports, newsletters, and on-line terminal access to the data. These 11 client services are aimed at the particular needs of specific participants within the electronics industry; these services and their relation to the infrastructure are illustrated in the chart that follows.

Semiconductor Industry Insights—Silicon to Systems draws from many of the Dataquest semiconductor industry services as well as other resources available to Dataquest and presents a high-level picture of the semiconductor industry for the 1989 and 1990 time frame. More detailed information on individual subjects is available from Dataquest through subscriptions to the appropriate service.

Figure i

Dataquest's Semiconductor Industry Services

Services	SUIS Semiconductor User Information Service	ASETS Asian Semiconductor and Electronics Technology Service JSIS Japanese Semiconductor Industry Service ESIS European Semiconductor Industry Service SIS Semiconductor Industry Service JSAM Japanese Semiconductor Application Markets ESAM European Semiconductor Application Markets NASM North American Semiconductor Markets SAM Semiconductor Application Markets MilAero MilAero Technology Service	SEMS Semiconductor Equipment and Materials Service
Audience	Semiconductor Buyers	Semiconductor Producers	Semiconductor Equipment and Materials Producers

Source: Dataquest (August 1990)

CHAPTER 1

Introduction

With the first-half results of 1990, the semiconductor industry appears to be emerging from an industry-wide recession that began in the third quarter of 1989. In 1989, worldwide semiconductor industry revenue was $57.2 billion. This amount represents a modest 12 percent growth over 1988 and a more than doubling of annual revenue in just four years since the 1985 recession.

Continued strength of the semiconductor industry in 1990, 1991, and beyond will depend on many worldwide factors, which include the following:

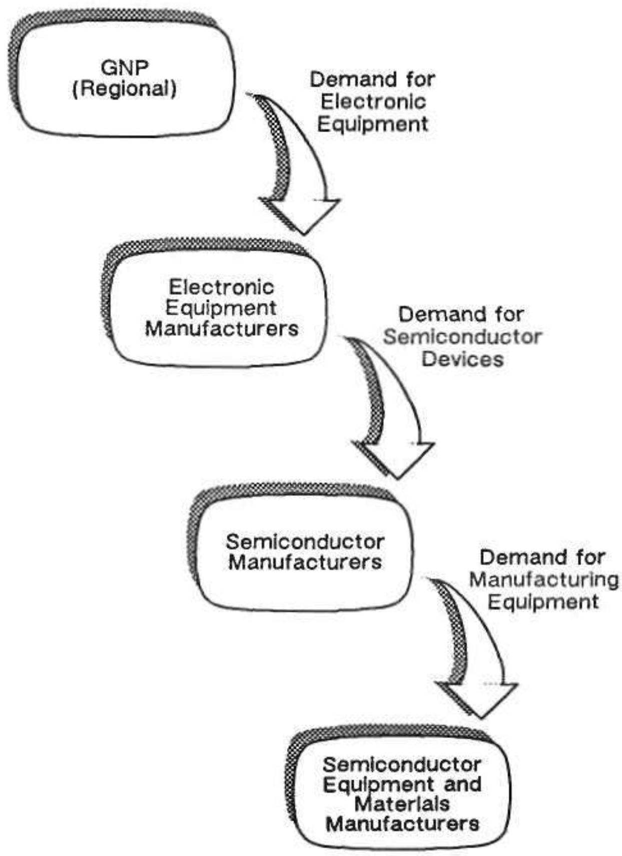
- The continued growth of the economies of the United States and its major trading partners
- The resulting capital spending—with its high content of electronic equipment—in the major industrialized regions of the world
- The continuing demand for semiconductors from producers of electronic equipment within each major industrialized region of the world
- The evolution of semiconductor manufacturing technology
- A continuing flow of new semiconductor products that enable innovative electronic products to stimulate the economies of all regions

Semiconductor Industry Insights—Silicon to Systems provides information and insights about how these factors combine to form and influence the industry infrastructure. These worldwide factors extend beyond the boundaries of companies, governments, and geographic regions. Implicit in these factors is a complex buyer-seller chain in which buyers create demand that pulls products through the chain. This complex chain consists of several tiers, beginning with the demand for electronic equipment, continuing to semiconductor devices, and ending with the demand for semiconductor equipment and materials. Demand for various products flows through the buyer/seller chain from one level to the next, producing a cascading "waterfall of demand," as shown in Figure 1-1.

This waterfall of demand is so fundamental to understanding the industry and the material presented that we have organized this report to follow the waterfall.

Figure 1-1

Waterfall of Demand



Source: Dataquest (August 1990)

Organization of this Report

Information, analysis, and insight are presented within each level of the waterfall so that the reader can understand the infrastructure as it relates to him or her. The issues and economic influences are quite different depending on the level within the waterfall where one sits. The perspective also is different based on whether one has an investor's, banker's, buyer's, or seller's point of view. Figure 1-2 illustrates the different perspectives within the electronics industry infrastructure. Interest in various sections of the report and levels of the waterfall will depend on the reader's individual perspective.

Additionally, investors, bankers, and other interested parties may be interested in all perspectives of the industry.

Chapters Follow the Waterfall

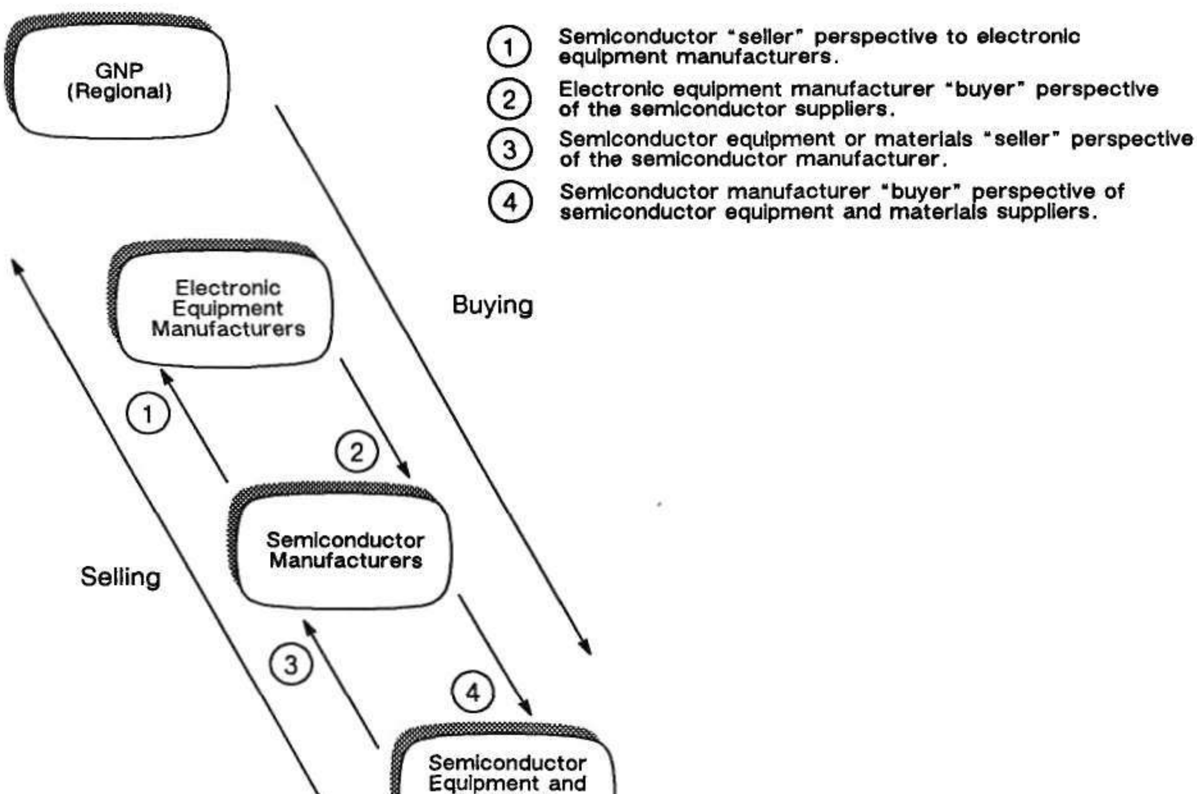
As stated earlier, the purpose of this report is to provide the reader with high-level, insightful analysis of the recent history and near-term future of the semiconductor industry.

Chapter 1 establishes the various reader perspectives and defines terminology.

Chapter 2 provides critical background information leading to 1989 semiconductor industry conditions and describes the industry infrastructure in terms of the demand waterfall.

Figure 1-2

Reader Perspectives



Source: Dataquest (August 1990)

Chapter 3 provides a review of the issues and trends that shaped the semiconductor industry in 1989 and a brief forecast of the worldwide and regional economic conditions. The individual regional economic conditions form the "headwaters" of the waterfall of demand and thus establish the demand and production levels of electronic equipment within each region.

Chapter 4 develops the relationship between regional economic factors and electronic equipment demand and production. The chapter ends with the worldwide forecast of semiconductor purchases by electronic equipment manufacturers.

Chapters 5 and 6 identify regional demand and production of semiconductor devices.

Chapter 7 presents the bottom levels of the demand waterfall, which are the resulting demand and production of semiconductor manufacturing equipment and materials.

Chapter 8 provides a summary of key issues and observations.

An investor or lender naturally will be interested in both the economic overview and resulting electronic equipment production forecast of Chapters 2 and 3, as well as the chapter presenting the perspective that matches his or her business interest.

Terminology and Definitions

Throughout this report, the terms "market," "consumption," "demand," "production," "output," "sales," and "revenue" have and will appear frequently. In addition, various economic terminology is used throughout. Precise definitions of these terms are given in the following paragraphs.

The terms "market," "consumption," and "demand" refer to the dollar value of products purchased within the specified geographical region, (e.g., North American and worldwide) regardless of where the products were manufactured.

The terms "production," "output," "sales," and "revenue" refer to the if-sold dollar value of products manufactured within the specified geographical region, regardless of where these products are purchased (i.e., purchased within the specified region or exported to another).

On the basis of the above definitions, assuming constant levels of inventory, worldwide production or sales equals worldwide demand or consumption.

The terms "real GNP" and "real GDP" refer to the gross national product and the gross domestic product of a country or major world region. The GDP is the total market value of all goods and services produced each year within the domestic borders of a country. The GNP equals the GDP plus the net of foreign investment income to domestic residents less income earned in the domestic market by foreign investors.

GNP/GDP also equals the sum of domestic demand plus exports minus imports. The three components of domestic demand are consumer spending, private fixed investment, and government spending.

The term "real" as applied to GNP, GDP, and other expressions refers to the value in constant prices prevailing in a reference year, which is 1982 for the US dollar. The term "nominal" as applied to GNP/GDP refers to the value at today's prices.

The terms "current account," "external account," or "external balance" refer to the difference between total exports and imports of goods and services, usually for one year.

The terms "private fixed business investment" and "private fixed nonresidential investment" both refer to investment in capital goods or capital spending by businesses and exclude residential investment. The term "private fixed investment" is the total of business capital spending and residential investment.

Dataquest Industry Classifications

Semiconductor Consumer Application Market Segments

Dataquest has categorized semiconductor consumers into the following six end-market application market segments:

- Data processing
- Communications
- Industrial
- Consumer
- Military
- Transportation

Semiconductor Product Classifications

Semiconductors are classified as either integrated circuits (ICs) or discrete devices. Within these classi- fications are further specific product definitions, outlined as follows, and illustrated in Figure 1-3:

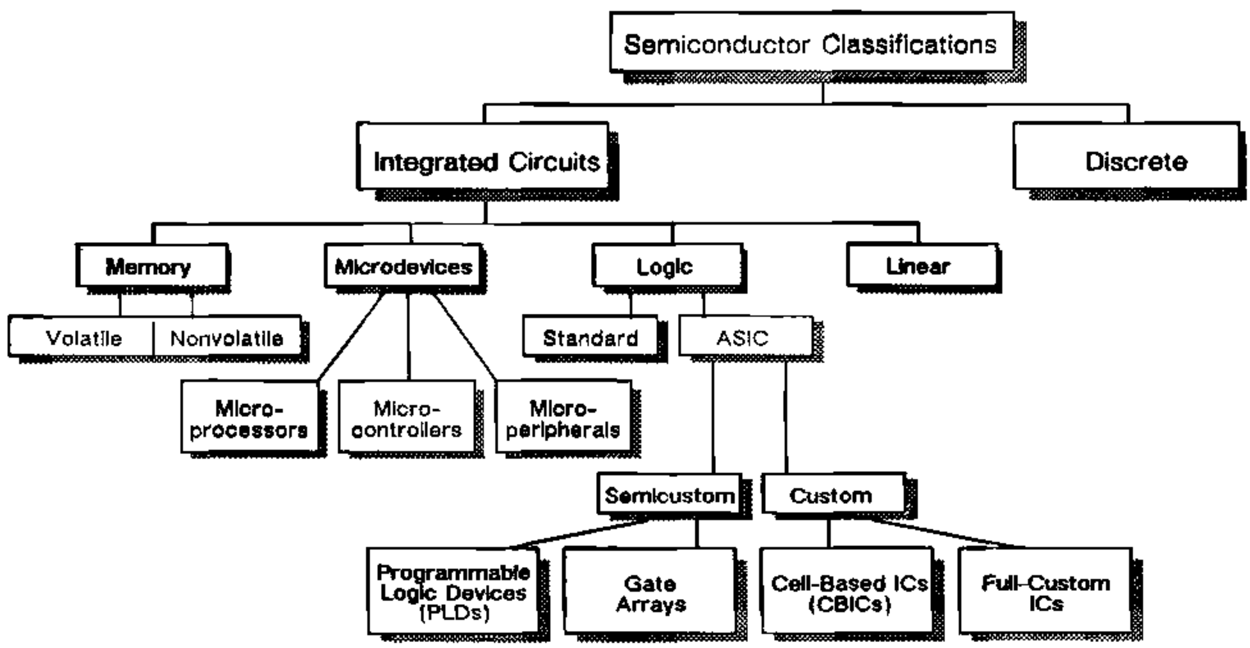
- Discrete devices are further classified as transistors, diodes, thyristors, optoelectronics, or other discrete devices.
- Integrated circuits are further classified into functions such as memory, microcomponents, logic, and analog.

All semiconductor devices are further classified by various process technologies, shown as follows:

- Bipolar digital—TTL, ECL, and others
- MOS—NMOS, PMOS, CMOS, and BiCMOS

Figure 1-3

Semiconductor Product Classifications



Source: Dataquest (August 1990)

CHAPTER 2

Critical Points in Understanding the Semiconductor Industry's Future

Critical to understanding the future of the semiconductor industry is an awareness of the events that have led the semiconductor industry to 1990 and knowledge of the electronics industry infrastructure that supports the semiconductor industry.

Historical Perspective: Events Leading to 1990

United States Launches the Semiconductor Industry

The launch of the semiconductor industry occurred when Bell Laboratories produced the first germanium transistor on December 23, 1947. By 1952, a number of companies in the United States were producing germanium devices commercially.

By the end of that decade, Texas Instruments (TI) had begun commercial production of silicon transistors. By then, the market topped $100 million in sales, primarily to the US Department of Defense (DOD) and to electronics companies for the manufacture of transistor radios.

Industry Expands to Worldwide Infrastructure

In 1959, Fairchild Camera and Instrument developed the planar technology for making transistors, which TI used in 1961 to produce the first ICs. Thus, the first decade of dynamic growth of the semiconductor industry was triggered.

Manufacturers worldwide began to integrate these new ICs into a variety of electronic-based products, and a worldwide chain of buyers and sellers to take semiconductors to market was established. Although the industry expanded to a worldwide infrastructure, the United States remained the dominant force in the infrastructure.

During the 1960s, semiconductor devices proliferated with small- and medium-scale integration (SSI, MSI). Logic families, such as the 7400 Series from TI, provided building blocks for electronic equipment and stimulated new electronic equipment designs. The demand for semiconductor memory began to rise in support of the logic building blocks. At the same time, major manufacturing technology advancements led to rapidly increasing device reliability and productivity. By the end of the decade, the industry was well on its way toward $2 billion in annual worldwide sales.

United States' Position in the Infrastructure Begins to Erode

The 1970s was the decade of low-cost electronic products. As the reliability and costs warranted, many companies used ICs to build such products as calculators, watches, or industrial, communications, and data processing equipment.

Early in the 1970s, US companies began to assemble their electronic products overseas to lower costs and expand their markets. European and Japanese markets, in addition to North American markets, became important to US manufacturers.

By the mid-1970s, US manufacturers were moving semiconductor production offshore to take advantage of lower costs and to be closer to the electronic assembly operations that had moved there earlier in the decade.

Metal-oxide semiconductor (MOS) ICs were the dominant products, and by the mid-1970s, large-scale integrated (LSI) devices were proliferating rapidly, further driving the low-cost electronic product era. As a result, worldwide industry sales were nearly $10 billion by 1979.

By the end of the 1970s, the semiconductor business was a worldwide industry with competition on an international scale. The emergence of very large-scale ICs (VLSIs) brought important new products such as microprocessors, read-only memories (ROMs), and erasable programmable ROMs (EPROMs). The age of personal computers and electronic games was born. That age was built on a whole new notion of super-low-cost electronics created by LSI and VLSI semiconductors. The low cost made the items price-sensitive and ideal for the low-cost structure of the offshore companies.

In fact, the offshore companies producing semiconductors for US industry were now proving to be capable competitors in all areas of manufacturing, as well as suppliers of low-cost products to the United States. Leadership of the semiconductor infrastructure that the United States had helped to create and had dominated now was being threatened.

Japan and Asia/Pacific Countries Begin to Dominate

Japanese electronic equipment producers seized upon US innovations in the 1970s and, leveraging their indigenous superior productivity, outproduced their US counterparts. Over the last 15 years, the very solution to the fundamental domestic competitive weakness—to move electronic product assembly offshore—has developed these offshore countries (Japan, South Korea, and Taiwan) into fierce domestic and international competitors. In the last half of the 1980s, these competitors gained the dominant share of world markets at all levels of the infrastructure that was built so impressively by the United States such a short time ago. For an example of Japanese dominance, see Figure 2-1. The strengths of Japanese and Asian companies are discussed further in Chapter 5.

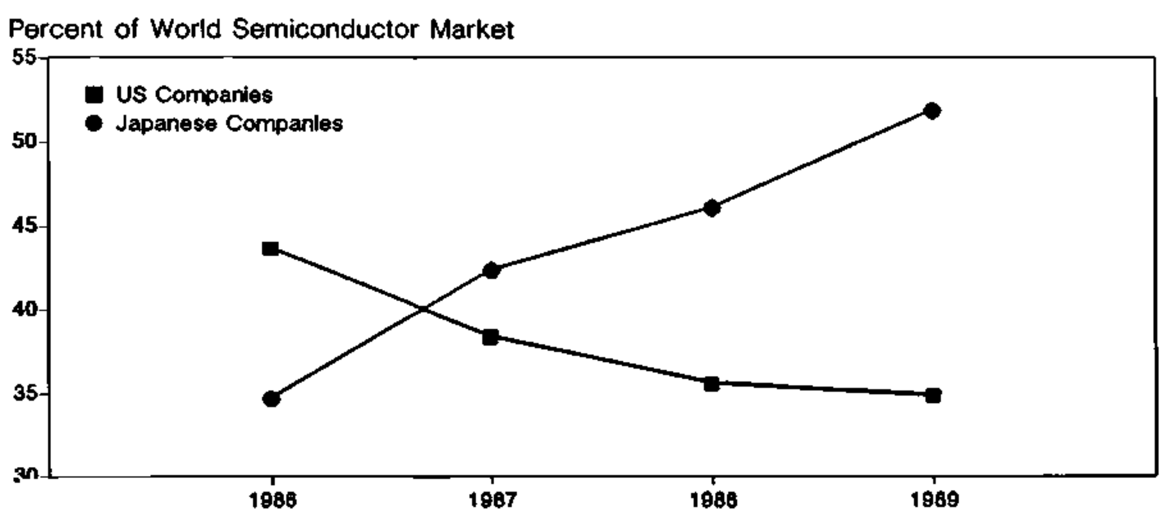
US Electronics Industry Faces a Critical Problem

As a result of losing their competitive edge, US companies are losing worldwide market share at all levels of the infrastructure; the loss now has become self-perpetuating. As the domestic companies lose share, they report declining growth rates and profits. These unfavorable results limit their access to investment capital, which limits the research and development (R&D) investment available to innovate the requisite new technologies that would regain a leadership position. As this process continues, the US semiconductor manufacturers face the following two-level problem:

- First, the US market for semiconductor devices is shrinking as a percentage of the worldwide semiconductor market (see Chapter 5).

Figure 2-1

US and Japanese Market Shares



Source: Dataquest (August 1990)

- Second, the Japanese and Asia/Pacific countries are gaining share of this shrinking worldwide market at the expense of the US producers' share, while not allowing much increase in US producers' share of their domestic markets.

This decline in competitiveness of the US electronics industry infrastructure is an issue of major concern to Japan, Europe, and other US trading partners for the following two reasons:

- The United States has been the primary source of semiconductor and system innovation since the beginning. Further competitive erosion could stall out that innovation and attract government and/or military interference in the market and/or promulgate adverse trade policies.

- Continued decline in the American electronics industry infrastructure could result in a significant recession of the US economy. Such a recession could eclipse the forecast consumption of a large volume of semiconductors and end products produced by Japanese and Asian manufacturers, leaving them with a severe drop in available market and significant overcapacity.

To sum up the conditions leading to 1990, the United States started the semiconductor industry, developed it into a huge worldwide industry, dominated it for several years, and now is at risk of becoming a minor player in the worldwide electronics market during the last decade of this century.

Electronics Industry Infrastructure: The Waterfall of Demand

The electronic industry infrastructure, of which the semiconductor industry is part, is made up of a complex chain of buyers and sellers working together to satisfy the worldwide demand for electronic products. This complex chain consists of several tiers, beginning with the demand for electronic equipment, continuing to semiconductor devices, and ending with the demand for semiconductor equipment and materials. Demand for various products flows through the buyer/seller chain from one level to the next, producing the cascading waterfall of demand shown in detail in Figure 2-2.

Knowledge of the infrastructure gives insight into how the various industry segments and the economy interact, specifically the following:

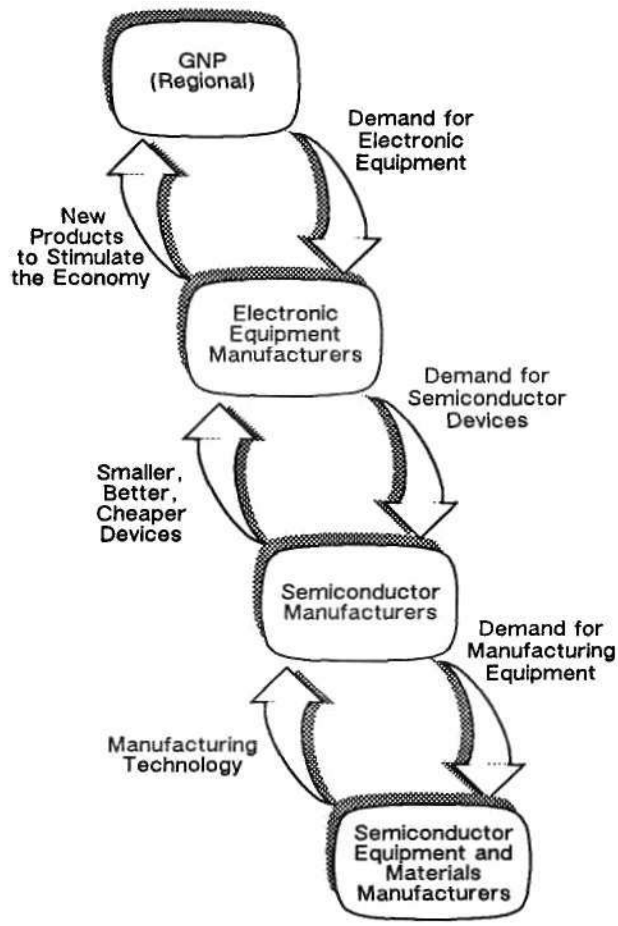
- How the demand of one industry segment affects the demand of the next industry segment

- How economic conditions affect the various industry segments

- How technology flows upward from one segment to the next and stimulates demand

Figure 2-2

Waterfall of Demand with Technology Flowing Upstream



Source: Dataquest (August 1990)

The Waterfall Headwaters: Capital Spending

As the worldwide economic climate changes, so does the worldwide demand for electronic equipment. The capital equipment spending sector of each region's economy has the largest influence on a region's demand for electronic products. This concept is developed in Chapter 4. Consumer and government spending have some impact, but to a much lesser degree. It is capital spending that forms the headwaters in the waterfall of demand.

Capital Spending Drives Electronic Equipment

Electronic equipment producers worldwide compete for their share of each region's demand. An equipment producer's ability to compete successfully in its domestic region or to export successfully to fulfill the demand of foreign regions depends largely on the economic climate of its domestic region. Economic factors such as exchange rates against other regions' currencies, relative interest rates, availability within the region of investment capital, and local labor costs determine the productivity and hence the competitiveness of producers located in a given region. The success of domestic producers in gaining share of the home region demand against importing competitors and in supplying foreign regions' demand via export determines the domestic producers' level of electronic equipment production.

Electronic Equipment Drives Semiconductor Demand

Electronic equipment production drives semiconductor demand. The supply to this demand can be of semiconductors produced within a local region or imported from other regions. The semiconductor production levels, profits, and resulting available investment capital of semiconductor companies within a region depends on their share of that region's total demand and their ability to export to fulfill demand from other regions. The success of a regional semiconductor manufacturer depends on many factors, but to a large extent, domestic economic conditions and access to foreign regions' demand are the key factors.

Semiconductor Production Drives Semiconductor Equipment

The resulting capital spending by regional semiconductor manufacturers creates the regional available market for the semiconductor equipment industry. Thus demand—driven by the worldwide economic climate and regional economic factors—begins with capital spending and flows down the waterfall until it reaches semiconductor equipment and materials establishing the waterfall of demand.

Technology Flows Upstream

In addition to demand flowing down the waterfall, technology flows upstream, as indicated in Figure 2-2. Technology provides the impetus for new products.

Manufacturing technology created by the semiconductor equipment manufacturers enables lower cost, lower power, and greater speeds in semiconductor devices. Competition in the semiconductor industry is based in part on manufacturing technology. Competitive attributes such as cost, size, and speed of a semiconductor device is dependent on several manufacturing factors, as follows:

- Yield—how many good devices can be produced in one manufacturing run—affects the costs.
- Integration—how many units of logic and/or memory can be contained in one device—affects both the size and speed of the device.
- Quality and turnaround time—additional factors that depend on manufacturing technology—affect every aspect of competitiveness.

Fundamentally, advances in manufacturing technology create the environment and the tools for continuing advances in semiconductor manufacturing. The productivity and competitiveness of any semiconductor manufacturer is critically dependent on access to state-of-the-art manufacturing equipment, which can come only from an economically and technically strong semiconductor manufacturing equipment industry.

Semiconductor manufacturers combined system design with manufacturing technology and produced semiconductor devices that have greater functionality at lower cost and with better reliability—for example, 32-bit microprocessors, application-specific ICs (ASICs), and 4Mb dynamic random-access memories (DRAMs).

New semiconductor devices allow the creation of new electronic equipment that has new functions, higher performance, and lower cost, and is physically smaller and more portable.

Creative new end systems open new end markets and stimulate end-product demand, thereby stimulating the economy.

Semiconductor Equipment Forms the Base

Figure 2-3 presents the worldwide forecast of electronics equipment production, the semiconductor production required to meet this equipment demand, and the capital spending required of the semiconductor producers to meet this semiconductor demand. Few may realize that 1989 resulted in worldwide electronic equipment production of $653.1 billion, which generated demand for more than $57.2 billion of semiconductor devices, resulting in $18.0 billion spent on semiconductor capital equipment. In other words, the $50.5 billion semiconductor equipment industry is the foundation of the $653.1 billion electronic equipment industry.

Summary

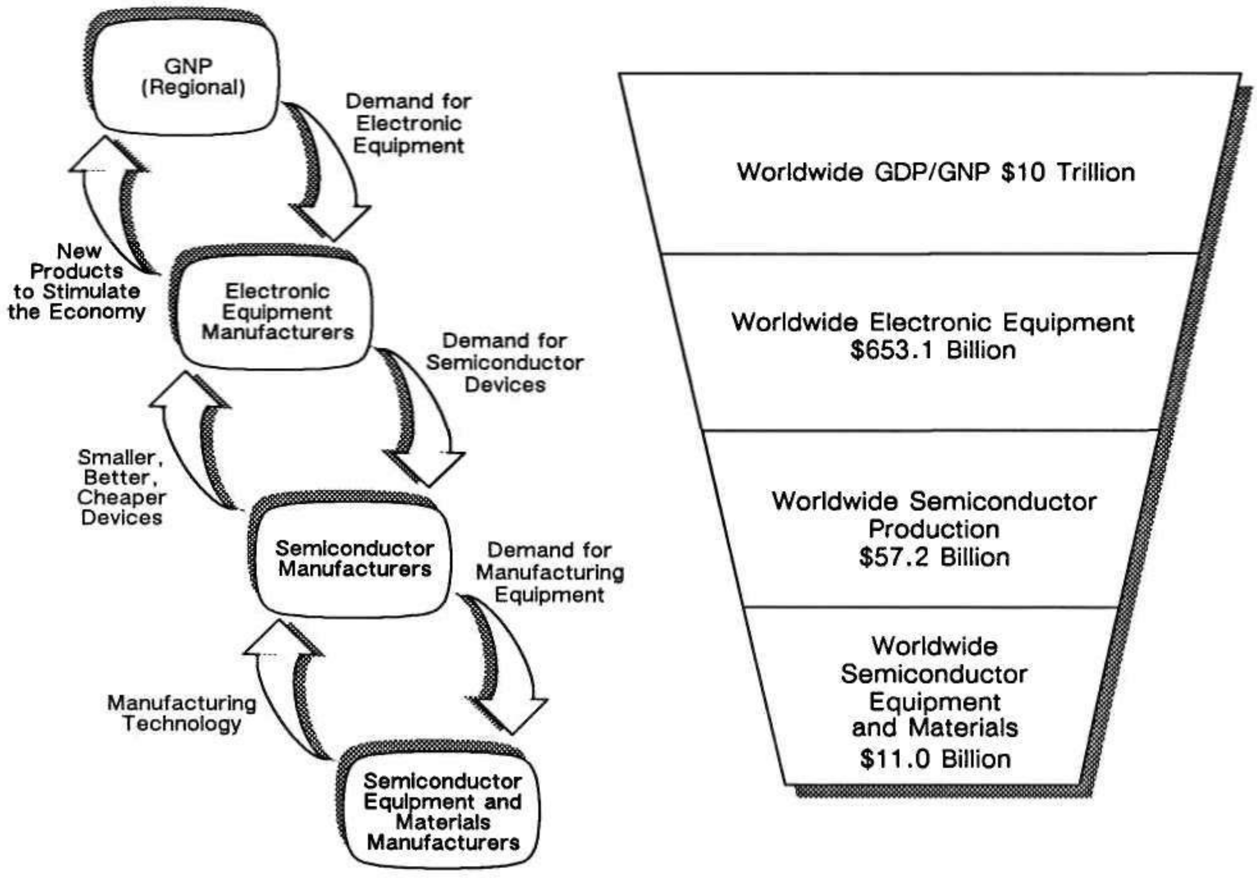
The following points are critical for developing an understanding of the semiconductor industry's future:

- US semiconductor manufacturers are at risk of exiting the stage in a play in which they designed, produced, and acted in the lead role.
- The US economy is dependent on its electronics industry.
  - The electronics industry is dependent on the semiconductor industry.
  - The semiconductor industry is dependent on the semiconductor equipment industry for necessary manufacturing technology.
- The worldwide economy is dependent on the worldwide electronics industry to produce new products to stimulate the worldwide economy.
  - The US electronics industry depends on both the US and worldwide economies.
  - The worldwide electronics industry is dependent on the global economy.

These observations are developed and discussed in succeeding chapters, beginning with global economic conditions and continuing through the production of semiconductor equipment and materials.

Figure 2-3

Base of the Waterfall



Source: Dataquest (August 1990)

CHAPTER 3

General Industry Climate 1989—The Year in Review

1989-1990: Off of the Escalator and into the Trough

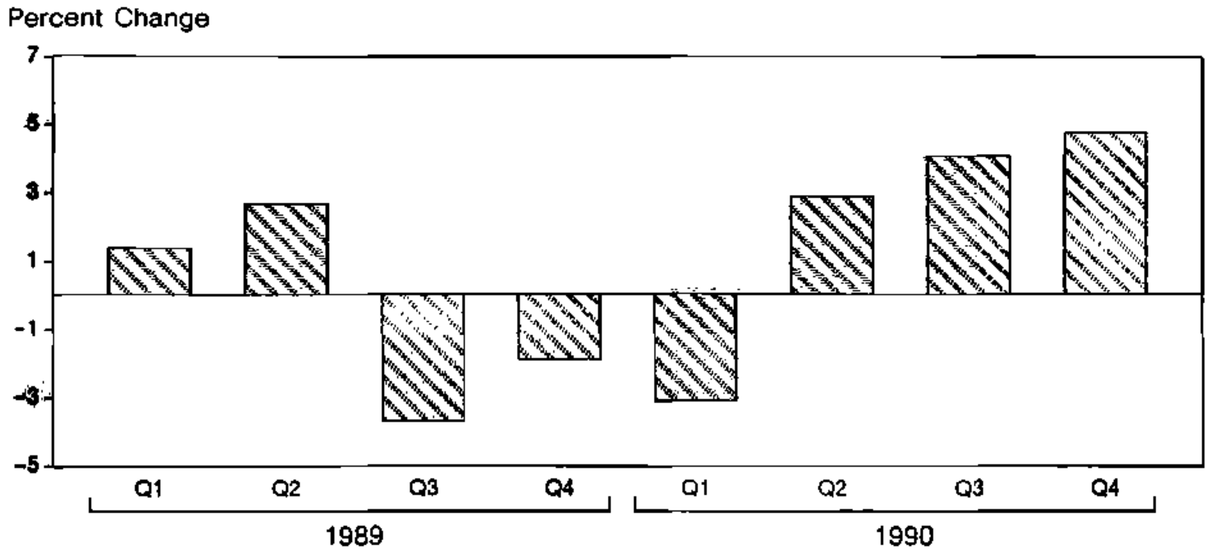
After realizing a growth rate of 33.0 percent in 1988, the semiconductor industry in 1989 posted positive growth rates in the first two quarters and then slumped into a recession in the third quarter (see Figure 3-1). Although industry growth rates for the third and fourth quarters of 1989 were negative on a quarter-to-quarter basis, only the fourth quarter posted a negative growth rate when compared with the fourth quarter of 1988. As a result, the industry posted a respectable 10.9 percent growth rate for 1989. First quarter 1990 was the last of three consecutive quarters of negative growth. Positive growth is expected on a quarter-to-quarter basis throughout the rest of 1990, but Dataquest estimates that the industry will realize a growth rate of negative 0.7 percent for 1990. Several factors influenced the performance of the semiconductor industry in 1989 and early 1990, including the following:

- Declines in real GNP growth rates
- Declines in consumer spending growth
- Declines in capital spending growth
- Declining growth rates for electronic equipment demand

The following paragraphs describe these factors and their effects on the semiconductor industry.

Figure 3-1

Quarterly Semiconductor Industry Growth Rates 1989-1990



Source: Dataquest (August 1990)

Economic Growth Eases

According to the International Monetary Fund, the real GNP growth rate for industrialized countries fell from 4.4 percent in 1988 to 3.5 percent in 1989. During that same period, consumer spending growth fell from 3.7 percent to 2.8 percent, and capital spending growth fell from 7.9 percent to 5.6 percent. Because the demand for semiconductors is a derived demand, driven by the demand for electronic equipment, declines in capital and consumer spending growth often translate to declining demand growth for semiconductors.

The following paragraphs briefly look at the economic performance of the four major industrial regions of the world.

US Economic Performance

Table 3-1 shows the actual and forecast GNP growth rates for selected countries from 1988 to 1991. Holding dollars constant, the US GNP growth rate was 3.0 percent in 1989, down from the 4.4 percent rate posted in 1988. On a quarterly basis, the GNP growth level fell from 3.7 percent in the first quarter to 2.5 percent in the second quarter. In the third quarter, the growth rate rebounded up to 3.0 percent. Finally, in the fourth quarter, a growth rate of only 1.1 percent was realized. GNP growth was 2.1 and 3.4 percent, respectively, for the first two quarters of 1990. According to economists at The Dun & Bradstreet Corporation, GNP growth is expected to be 2.6 percent in the third quarter of 1990 and 3.9 percent in the fourth quarter. D&B forecasts a 3.0 percent growth rate in GNP for the year.

Japanese Economic Performance

In 1989, real GNP rose 4.8 percent in Japan. Although lower than 5.8 percent growth in 1988, 1989 growth still was very respectable. The Japanese economy slowed because of weaker consumer spending, which was partly due to the imposition of a new sales tax and a deterioration of the Japanese trade surplus. Growth in business investment continued at a strong pace, expanding 17.7 percent in 1989, up from 15.5 percent in 1988. Business investment growth is expected to fall to approximately 10.0 percent in 1990. In addition, real GNP growth is expected to fall to 4.0 percent in 1990.

European Economic Performance

Taken as a whole, the four major European countries (France, Italy, the United Kingdom, and West Germany) experienced a real GNP growth rate of 3.4 percent in 1989, down from 3.8 percent in 1988. Of these four countries, only West Germany realized an increase in real GNP growth, from 3.6 percent in 1988 to 4.0 percent in 1989. In 1990, real GNP growth is expected to fall further to 2.8 percent.

Table 3-1

Annual and Forecast GNP Growth for Selected Nations
1988-1990
(Percent Change from Previous Year)

Country	1988 GNP	1989 GNP	1990 GNP	1991 GNP
United States	4.4%	3.0%	2.5%	3.4%
Japan	5.8%	4.8%	4.0%	3.9%
France	3.8%	3.7%	3.2%	3.4%
West Germany	3.6%	4.0%	4.0%	3.5%
United Kingdom	4.6%	2.3%	1.5%	2.5%
South Korea	11.3%	6.1%	5.5%	6.5%
Taiwan	7.3%	7.4%	6.5%	7.0%
Singapore	11.2%	9.2%	7.5%	7.0%
Hong Kong	7.3%	3.5%	4.0%	3.5%

Source: The Dun & Bradstreet Corporation

Asian Economic Performance

As in the other regions of the world, real GNP growth in Asia fell in 1989 from its 1988 levels. In South Korea, real GNP growth fell from 11.3 percent in 1988 to 6.1 percent in 1989. Taiwan experienced higher GNP growth, rising from 7.3 percent in 1988 to 7.4 percent in 1989. In Singapore, the double-digit GNP growth rate of 11.2 percent in 1988 gave way to a growth rate of 9.2 percent in 1989. Finally, in Hong Kong, the 1989 GNP growth rate of 3.5 percent was less than one-half of the 7.3 percent recorded in 1988. GNP growth rates throughout the region are expected to decline once again in 1990.

Electronic Equipment Slowdown

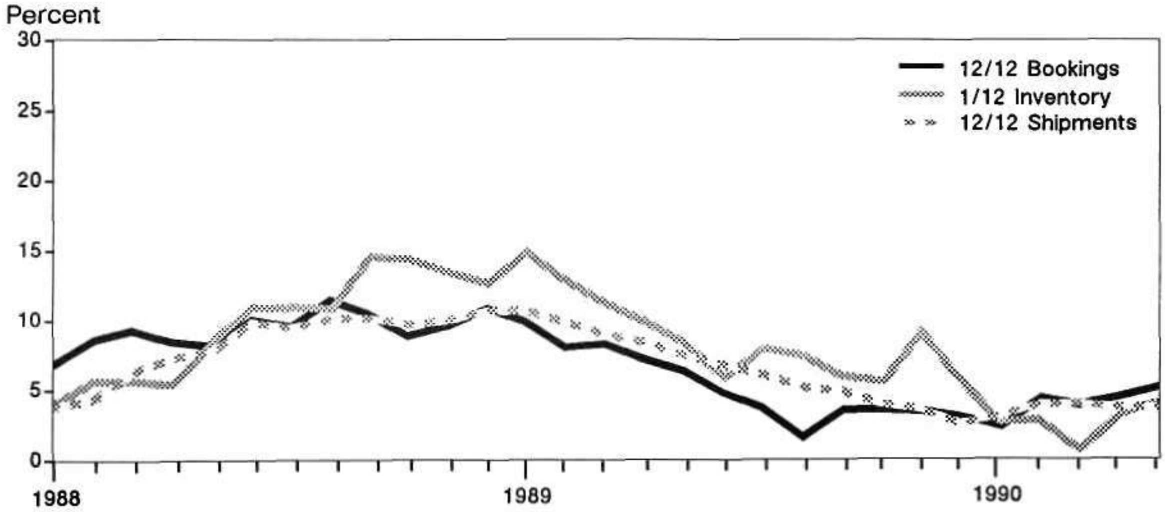
Monthly data from the US Department of Commerce (DOC) shows that bookings and shipments rates of change for the computers and office equipment, and electronic instruments segments generally declined through 1989 when measured on a 12/12 basis. The rate of change of growth in computers and office equipment shipments declined for 12 consecutive months, beginning in January 1989 with a 12/12 growth rate of nearly 11.0 percent, before bottoming out in December 1989 at 2.8 percent (see Figure 3-2). At the same time, 12/12 bookings showed continuous decline from 11.1 percent in December 1988 to 1.9 percent in August 1989. More disturbing than the mere declines is the fact that computer and office equipment orders, on an annualized basis, have fallen from a growth rate of approximately 10.0 percent in January 1989 to only 4.0 percent in March 1990.

1989 Forecast and Outcome

In a February 1989 newsletter entitled "Worldwide Semiconductor Outlook: First Quarter 1989," Dataquest forecast modest growth in the semiconductor industry for the first two quarters of 1989 followed by three negative quarters beginning in the third quarter of 1989, as memory prices fell and the US economy softened slightly. In reality, the worldwide semiconductor market grew 1.4 and 2.7 percent, respectively, in the first two quarters of 1989. As we predicted, the third and fourth quarters showed negative growth, declining 3.7 and 1.9 percent, respectively, on a worldwide basis. The overall, worldwide year-to-year growth rate was 10.9 percent in 1989.

Figure 3-2

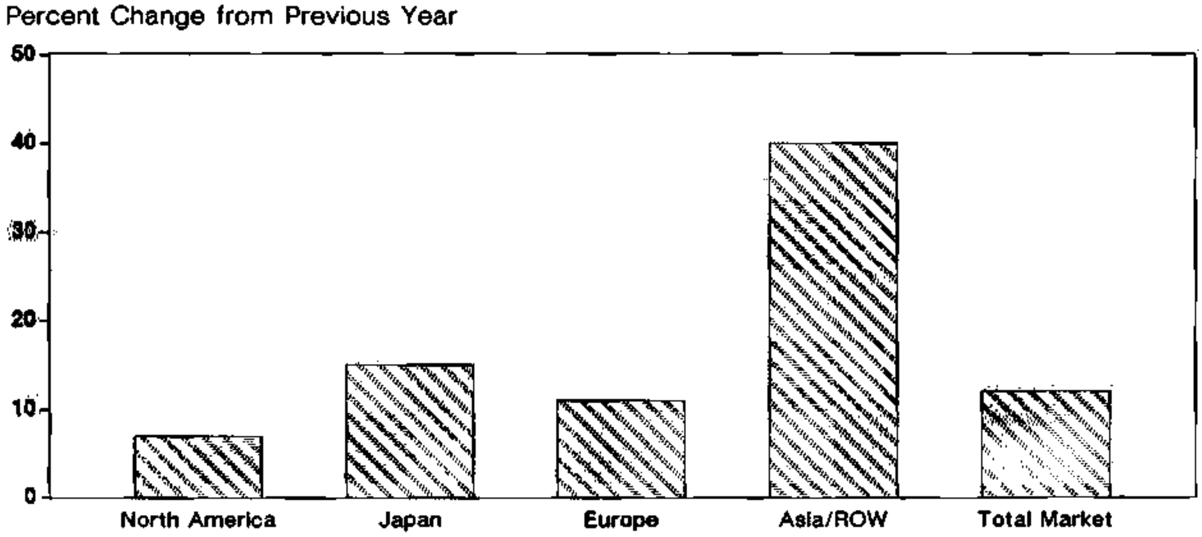
Computers and Office Equipment
Rate of Change
1988-1990



Source: US Department of Commerce

Figure 3-3

Semiconductor Production Growth by Region—1989



Source: Dataquest (August 1990)

Performance of the North American and European markets mirrored that of the worldwide market. Both regions showed positive, albeit moderate, growth in the first half of 1989, followed by two quarters of negative growth in the second half of the year. The Japan and Asia/Rest of World (ROW) regions differed slightly in their performance. In each of these regions, the first quarter was one of negative growth, followed by a positive second quarter, and negative growth in the third and fourth quarters. All four major regions experienced at least moderate growth for the year, however, as is depicted in Figure 3-3.

1989 US Book-to-Bill Analysis

As expected, the US semiconductor book-to-bill ratio generally followed the industry trend of slow first-half growth followed by negative second-half growth (see Figure 3-4). Beginning with a ratio of 1.02 in January 1989, the book-to-bill ratio remained above parity until June, when it fell to 0.98. The ratio climbed above parity again in December, and has remained above 1.0 since that time. As stated previously, US electronic equipment sales growth slowed throughout 1989. When combined with tighter inventory controls, the result was a decline in semiconductor orders in the second half of 1989.

US semiconductor billings for the first half of 1989 increased 20.3 percent over the same period in 1988. During the second half of the year, low inventory levels, particularly in non-DRAM products, caused an increase in spot purchases, which increased "turns" business. The effect of increased "turns" business is usually more intense competition and price pressure, which only makes market declines more severe. DRAM price declines also contributed to the decline in the US market.

Despite the declining book-to-bill ratio, monthly billings showed positive year-to-year growth for each month in 1989. In fact, only the fourth quarter of 1989 showed negative growth on a year-to-year basis.

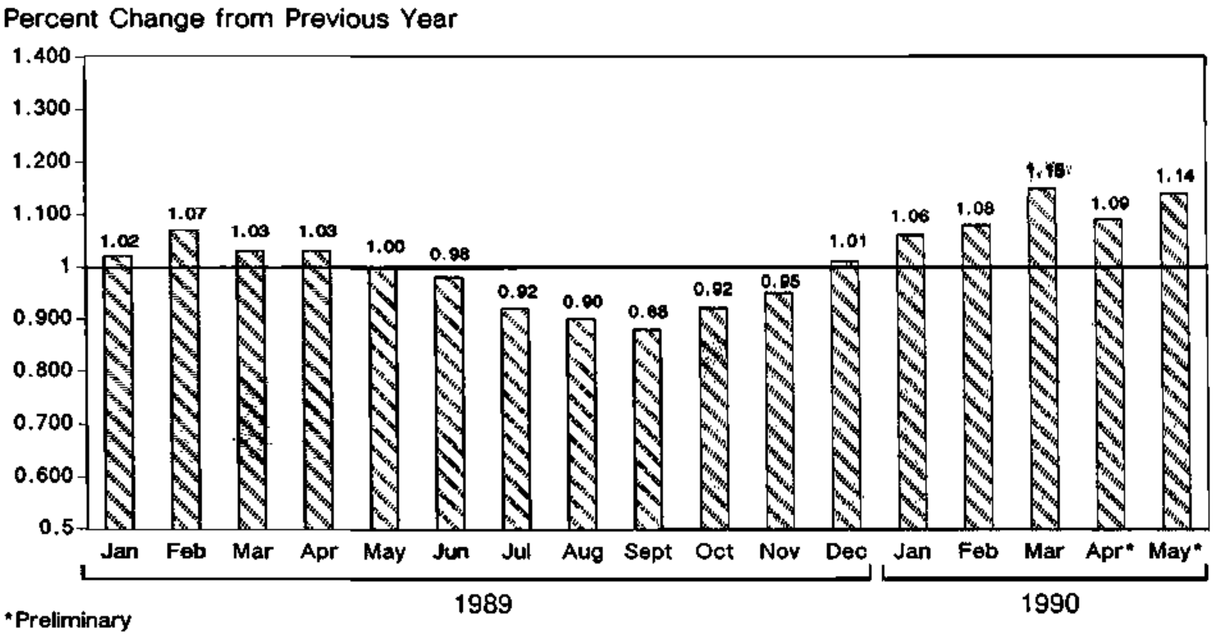
Product Summaries

Analog ICs

The year 1989 was a tough one for many analog suppliers. More than a tough year, it was a historic year in which analog IC segments experienced a significant downturn while many of the digital segments had a softer landing. This effect was the opposite of past trends where the stability of the analog IC market had made it more insulated from market deterioration than the more volatile digital IC market.

Figure 3-4

US Semiconductor Book-to-Bill Ratio
1989-1990



Source: Dataquest (August 1990)

During 1989, unit sales of analog ICs increased while average selling prices (ASPs) declined, leading to a very weak revenue growth for the year. A significant ASP decline in commodity linears (largely op amps and voltage regulators) starting in mid-1988 flattened revenue growth in 1989 despite the fact that unit growth continued through 1988 and 1989. Consumer-specific IC consumption declined as the consumer market for VCRs, camcorders, CD players, and other entertainment products softened. Because consumer products represent 40 percent of analog IC sales, the softness of the consumer market impacted the analog IC market significantly.

Dataquest has observed digital signal processing (DSP) entering into more mixed-signal products, replacing analog signal processing. One product segment that showed significant growth in 1989 was that of delta sigma ADC converters. Several new delta sigma converters were introduced in 1989, many for microprocessor (MPU)-based and digital/audio applications. The growth of this market is driven by growth in digital/audio systems, which also has driven substantial unit growth in digital-to-analog converter (DAC) markets. Palette DACs and digital audio DACs were two of the more noticeable winners in the 1988 market. In 1989, an avalanche of competitive products brought down ASPs, severely impacting the data converter segment.

The year was marked by a trend toward mixed-signal ICs. This trend is driven by continuing growth in digital products, which need mixed-signal ICs to simplify complex interfaces. Perhaps the biggest disappointment of 1989 was the fact that mixed-signal ASICs did not live up to the tremendous media attention and marketing hype. The revenue still is relatively small, profits are nonexistent, and tool and test issues cloud future growth. Companies that have experimented with mixed-signal ASICs have not fared well. Dataquest has identified a trend among original equipment manufacturers (OEMs) away from ASICs toward application specific-standard products (ASSPs). As mixed-signal ICs gain popularity, these more complex ICs, with increased analog integration, will reverse the general trend toward sagging ASPs, providing increased analog revenue growth and bringing unit growth more into line with revenue. Despite this upward pressure on selling prices, Dataquest expects commodity linear op amps, regulators, and interface ICs to continue their downward trend.

ASICs

In 1989, the ASIC market grew 10.9 percent, slightly below the growth rate of 12.0 percent posted for the total semiconductor market. Gate arrays dominated the market, growing from 40.0 percent of the 1988 ASIC market to 42.0 percent in 1989. The next largest 1989 ASIC market was full-custom ICs with 31.0 percent, followed by cell-based ICs (CBICs) with 18.0 percent and programmable logic devices (PLDs) with 9.0 percent.

Gate arrays offer many advantages over full-custom ICs and CBICs. Key gate array advantages include quicker time to market, lower risk, and lower design cost. In 1989, gate arrays won the design-win battle over CBICs. However, 1989 gate array pricing was cutthroat as suppliers battled for market share. The aggressive pricing was true even in submicron geometries. In the past, Dataquest observed price premiums for next-generation parts; this no longer seems to hold true. Because of disappearing price premiums, profits in the gate array market were very slim despite a 16.0 percent revenue growth. Through gate arrays, ASIC silicon has become a commodity item, and ASIC tools are becoming commodity items. The only way suppliers are able to differentiate themselves is through their libraries of application-specific building blocks. In the future, the companies with strong applications experience are the ones that will be profitable.

The use of CBICs has been limited by the dominance of gate arrays to high-volume, very high performance, or special functions such as mixed-signal applications. However, in the development of standard products, the CBIC is replacing the full-custom IC as the accepted design methodology.

Simple PLDs (GAL- and PAL-type devices) are no longer outperforming the market; they are now growing with the market. As the popularity of bipolar PLDs wane, the rapidly growing CMOS PLD market is becoming quite crowded. The market for complex PLDs (e.g., FPGAs) is showing tremendous growth and is expected to nearly double in 1990. The growth of this market is equivalent to that of the MOS gate array market at a similar stage in the product life cycle. This market remains wide open, because no standards have been developed yet.

Memory Products

In 1989, the memory market continued to dominate the worldwide semiconductor market. Despite tumbling DRAM prices, the MOS memory market grew an astonishing 45 percent in 1989. Were it not for the strength of the memory market, in particular the inflated DRAM prices in the first half of the year, the slowdown the industry experienced in late 1989 and early 1990 could have been much worse.

Perhaps the biggest story of 1989 was the DRAM shortage and subsequent oversupply situation. At the beginning of 1989, a series supply shortage existed for 256K and 1Mb DRAMs. First-tier Japanese DRAM manufacturers reaped high profits with their strategy of managing supply to control prices. As the year continued, however, the supply shortage transformed into an oversupply situation. As demand slowed and South Korean and US manufacturers brought new products on-line, supply was able to meet demand in the third quarter before resulting in an oversupply of DRAMs. As a result of this situation, DRAM prices fell dramatically from their earlier levels. Volume prices for 1Mb DRAMs, for example, fell from approximately $18 in the first quarter to the $7 to $8 range by year's end. One of the more significant developments that arose in the DRAM market during 1989 as a fallout of the shortage was Samsung's growth as a DRAM supplier. Samsung was able to take advantage of the supply management tactics of the larger vendors and the market slowdown to become the number three supplier in the DRAM market. Another fallout of the DRAM shortage was the formation of U.S. Memories, a consortium formed to provide the United States with a domestic source of DRAMs. A full review of the rise and fall of U.S. Memories is provided in the section entitled "Key Industry Events and Issues." In 1989, the memory market proved itself to be a very volatile market, one that can quickly change from a shortage to an oversupply situation.

During 1989, we saw the early introduction of the 4Mb DRAM. This introduction marked the emergence of 0.8-micron CMOS line geometries into full-production lines. Hitachi and Toshiba were the unquestioned early leaders in the production of 4Mb DRAMs.

In slow SRAMs, we observed significant price degradation following a three-month lag behind DRAMs. This pricing relationship is due to the close ties between SRAMs and DRAMs from a manufacturing standpoint. As the oversupply situation developed in the DRAM market, manufacturers shifted capacity toward other devices including slow SRAMs, PSRAMs, nonvolatile memories, and ASICs. Both types of SRAMs are tied to DRAM capacity, although slow SRAMs are more closely tied. Therefore, although we saw price erosion in the fast SRAM market, it was not as severe as that in the slow SRAM arena.

The markets for specialty memories became quite crowded in 1989. In the market for SRAM-based deep first-in, first-out (FIFO) products, for instance, the number of suppliers grew to 18, servicing a market that totaled only $70 million. In the same way, the number of suppliers to the dual-port SRAM market grew to 9—quite a few for an $18 million market. As a result, Dataquest observed significant price erosion in these markets.

In 1989, BiCMOS memories also continued to grow. The three market leaders were Hitachi, National Semiconductor, and Fujitsu. Most of the main users of BiCMOS memory are suppliers of supercomputers and large mainframes that use BiCMOS SRAMs as main memory or large secondary caches. Unfortunately, 1989 also saw the death of Saratoga Semiconductor, a US supplier of BiCMOS memories.

Microcomponents

In 1989, the worldwide market for microcomponent products slightly outperformed the total semiconductor market with a growth rate of approximately 13 percent. The year was highlighted by several significant product trends.

The major battle lines in the reduced-instruction-set computing (RISC)-based market have formed around four camps: Intel's i80860, MIPS Computer Systems' R3000, Motorola's 88000, and Sun's SPARC architecture. Both Sun and MIPS were busy licensing their architectures to eager semiconductor vendors. Toshiba announced an agreement to team up with Sun Microsystems to develop low-cost, higher-performance computers using the SPARC architecture and SunOS UNIX operating system. LSI Logic, which teamed up with Sun to develop the SPARCstation 1 single-board RISC system, announced in early 1990 that it is producing a SPARC chip set that will facilitate the production of SPARC-compatible workstations. In 1989, MIPS Computer Systems announced long-term agreements with both NEC and Siemens to license its RISC microprocessors for manufacturing, marketing, and support worldwide. Currently, the major battle for dominance is between SPARC and MIPS architectures. With a total of 12 vendors (6 embracing each architecture), the competition for RISC sockets has become very intense.

Perhaps the major driving force in the microcomponent industry in 1989 was the realization that PC-related products can offer significant volumes and revenue. This fact was most visible in the market for PC chip sets. During the past two years, the PC logic chip set market has been the fastest-growing segment of the microcomponent market. Worldwide, there were only 6 PC logic chip set vendors in 1987. In 1990, there are more than 30. Dataquest believes that the rapid increase in new entrants and capacity has carried this market to the point of saturation. We expect this saturation to lead to aggressive price competition, causing vendors to look for penetration of these products into new applications and markets. We believe that this rapid market saturation is bound to be repeated in each of the PC peripheral chip set markets—logic, graphics, communications, mass storage, modem, and fax—as established chip set and semiconductor companies follow one another into these obvious product-line extensions. At the same time, the apparently low barriers to entry invite many new participants. The graphics chip set market already is showing signs of saturation, marked by severe pricing pressure.

Another PC-related market that has exhibited increased competition and drawn increased media attention is the floating-point coprocessor market. Traditionally, Intel, Motorola, and Weitek have dominated the market for floating-point units (FPUs). For potential entrants to the compatible coprocessor market, the current low level of penetration into available sockets, combined with artificially high prices and margins, is an attractive inducement to entry. Until recently, no vendors have offered parts that are plug-compatible with Motorola or Intel devices. Weitek has achieved success in the high-end coprocessor market, but has not offered plug compatibility to the Intel architecture. In 1989, two start-ups, Cyrix Corporation and Integrated Information Technology

(IIT), introduced devices that are plug-compatible with Intel's 80X87 products. As these start-ups begin to challenge Intel's dominance in this market, we have witnessed increased marketing hype and price cutting by Intel in an effort to protect its market share.

Many manufacturers, including Intel and most RISC vendors, have entered the 32-bit embedded control market. In general, the embedded control market is easier to compete in than that of reprogrammable processors, which often require name recognition and binary compatibility with existing products. The key to competition in the embedded control market is the cost effectiveness of the part, which includes price, space taken up on the board, the number of required peripherals, and the required software. As is true with many other products, however, there is a significant lag period between the introduction of a product (32-bit processors in this case) and the availability of sockets and large sales volumes. Unfortunately, vendors in the 1989 and 1990 market for 32-bit embedded control are caught in this lag period. At this time, only a limited number of available sockets exist, and revenue is very low. Dataquest believes that this situation will change, but probably not until 1991. In April 1989, Motorola introduced the industry's first 32-bit microcontroller (MCU). Motorola is the company to watch as the 32-bit embedded control market heats up.

Key Industry Events and Issues

U.S. Memories

On Wednesday, June 23, 1989, a new company called U.S. Memories announced its intention to become the fifth US-owned, noncaptive supplier of DRAMs. The company was to be a jointly owned venture funded initially by seven major US electronics and semiconductor companies. The companies contributing seed money to the start-up were AMD, DEC, Hewlett-Packard, IBM, Intel, LSI Logic, and National Semiconductor.

The new company was headed by Sanford Kane, who resigned from his position as vice president of technology at IBM to become the president and CEO of U.S. Memories. The new entity hoped to meet its $1 billion funding requirement and select a site by the end of 1989. The company stated a goal of building a wafer fabrication facility that will begin full-volume production of 4Mb DRAMs by the first half of 1991. However, between U.S. Memories and its vision of high-volume, leading-edge DRAM manufacturing in the early 1990s existed a number of hurdles. These hurdles included successfully addressing potential antitrust barriers, convincing other systems and components companies that they have a vested interest in participating in the new venture, and overcoming a late start in the 4Mb DRAM market, particularly in relation to Japanese competitors.

Indeed, the antitrust issue was raised and was a source of great controversy in Washington D.C. One of the a priori conditions of U.S. Memories' formation was the modification of the Sherman Antitrust Act of 1890 so that US companies can more easily form manufacturing consortia. Although existing legislation allows consortia to engage in R&D activities and provides immunity from antitrust damages for export-only consortia, these measures do not address the issues raised by U.S. Memories. A number of bills under consideration in the House of Representatives would apply some measure of antitrust immunity to manufacturing consortia.

In the end, the funding, site selection, and antitrust obstacles became moot issues. On January 15, 1990, Sanford Kane announced the dissolution of the consortium. Mr. Kane explained that U.S. Memories was a strategic approach that could have worked, but with the exception of solid support from IBM and DEC, there was inadequate response from the rest of the computer industry.

In forming U.S. Memories, Kane successfully mastered the challenges of producing a business plan, obtaining an agreement with IBM to license its 4Mb DRAM design and process technology, narrowing down the selection of a plant site, and obtaining a favorable opinion regarding antitrust issues. But in the end, he could not convince enough DRAM users to cumulatively invest $500 million and guarantee to purchase at least 50 percent of USM's DRAM output. Even on its deathbed, USM made one final effort with a revised plan wherein the total equity investment required from the participating computer manufacturers was scaled down to $150 million. However, the purchase guarantees rose from 50 percent of USM's output to 75 to 80 percent of the output, and an additional $200 million of equity was to be raised from external institutional investors. This plan was submitted to 11 interested companies—the 7 original investors, and 4 others: AT&T, Compaq Computer, NCR, and Tandem

Computers. At a meeting on January 10, the revised proposal could not garner sufficient support, so the decision was made not to continue with U.S. Memories.

The speakers at the January 15 press conference said that the impetus for the formation of a U.S. Memories came from an "urgent request" from the AEA and SIA that the domestic computer industry wanted an indigenous company that could supply 40 percent of its DRAM requirements within a reasonable time. USM's mission was, simply put, to provide a domestic source for an assured, stable supply of DRAMs while also offering an attractive return on investment. The computer companies' cry for a domestic supply of DRAMs was driven by the difficulties experienced from 1987 through the first half of 1989 when 1Mb DRAMs were scarce and expensive. However, by the time USM's funding effort had gained momentum, the bottom had dropped out of the 1Mb DRAM market, and the industry was flooded with parts. The passion for a domestic DRAM supplier had waned, and the computer manufacturers had forgotten about last year's problems.

Dataquest is aware of other ongoing efforts to establish a sizable US-based memory capability. Approaches such as that taken by Texas Instruments with its vendor alliances may also serve as a more workable model. We believe that a series of alliances between memory consumers and major US-based memory producers that are willing to make significant investment will occur in the 1990s, albeit in more focused relationships.

SEMATECH

In August 1987, SEMATECH announced its incorporation. The SEMATECH mission statement is both concise and powerful: "To provide the US semiconductor industry the domestic capability for world leadership in manufacturing." SEMATECH defines its role in fulfilling its mission in terms of "the three Ds and a T": Define, Develop, Demonstrate, and Transfer, which are described as follows:

- Defining and coordinating programs—Along with the collective resources of its member companies, SEMATECH analysts perform competitive analysis aimed at identifying critical manufacturing technologies required to reach the consortium's goal of worldwide manufacturing leadership for the US industry. SEMATECH further defines its role as "prioritizing resources for maximum impact." This impact would come through programs that address "show stoppers" (critical tools and materials to which the United States is in danger of losing access), "key enablers" (tools and methods that would give member companies the largest advantage in the shortest time), and "high-risk/high-return manufacturing approaches."
- Developing world-competitive manufacturing capability—From its definition of programs, SEMATECH creates equipment specifications, selects suppliers with which it contracts for the delivery of equipment based on its specifications, shares in the development work of its SEMI/SEMATECH companies, and sets standards for manufacturing equipment integration.
- Demonstrate capability—SEMATECH's Austin, Texas, fab is charged with providing engineering characterization and manufacturing proof for the equipment and materials developed under its direction. The consortium's means of providing "proof of manufacturability" are based on its "manufacturing demonstration vehicles" (MDVs), the 4Mb DRAM and 64K fast SRAM processes provided by IBM and AT&T, respectively.
- Technology transfer—The final and most critical ingredient to SEMATECH's success rests in its ability to document its projects and to develop training programs that successfully transfer the derived technology benefits to its member companies. Essential to successful technology transfer is the participation in SEMATECH from the member companies.

As the preceding explanation of the SEMATECH philosophy makes clear, SEMATECH does not see itself so much as the originator of manufacturing technology R&D but rather as the coordinator and facilitator of such efforts by an existing US semiconductor equipment and materials vendor base. Where the rubber meets the road in the SEMATECH program is through the allocation of the consortium's $200 million-a-year budget to this vendor base in the form of contract awards. Currently, most of these contracts either are Joint Development Projects (JDPs) aimed at the development of new manufacturing techniques, materials and equipment, or Equipment Improvement Programs (EIPs) aimed at the improvement of existing tools.

Up to the beginning of 1989, the largest portion of the SEMATECH budget was devoted to the construction of facilities and the purchase of capital equipment. With its clean room constructed and the majority of its permanent employees and member-company assignees in place, SEMATECH's gathering of momentum has been obvious through 1989. Less than 15 months after the selection of its Austin, Texas, site, SEMATECH announced the first run of functional 64K SRAM silicon in March 1989, thus establishing its initial baseline process as outlined in its Phase I goals. The increased funding that became available for joint development and equipment improvement programs at the start of last year is clearly reflected in the pace of SEMATECH contract awards observed by Dataquest since the first contracts were awarded in May 1989.

An indication of SEMATECH's contract priorities can be found in its 1989 Operating Plan. Based on its 1989 goals, SEMATECH identified the following release schedule for external development contracts:

- First quarter: e-beam mask making system, I-line resists, planarization technology

- Second quarter: deposition systems, DUV steppers and resists

- Third quarter: lithography cluster

- Fourth quarter: inspection systems

Viewed against these priorities, Table 3-2 provides a chronological look at SEMATECH's contract awards from May 1989 to April 1990. The number of contracts since fall 1989 should probably serve as a good indicator of future SEMATECH contract activity, because in its 1990 Operating Plan, SEMATECH stated that "Labor, operating, and facilities costs will have reached steady-state by the end of FY 1989" (SEMATECH's fiscal year begins in October). At present, between 35 and 40 percent of the total SEMATECH budget is dedicated to development contracts.

Litigation

In 1989, a number of lawsuits were filed as semiconductor manufacturers attempted to protect their intellectual property. It has become obvious that intellectual property, marked by patents, is a very valuable asset in today's semiconductor market. The two most prominent court cases of 1989 involved lawsuits filed by Intel and Motorola against NEC and Hitachi, respectively.

After a legal battle that lasted nearly five years, Intel's suit against NEC for infringing on Intel's copyright claim to its 8088/86 microcode was resolved in 1989. In February 1989, Judge William Gray decided that although Intel had a valid copyright claim to its microcode, it forfeited its copyright to a lack of diligence in monitoring the affixing of copyright notices. The big decision, however, was that NEC was held to be innocent of copying Intel's microcode in its V-Series microprocessors. By December 4, 1989, all outstanding issues in the litigation had been resolved. As part of the settlement, NEC's claims for unfair competition, which were to come before the court in January 1990, have been dismissed. Further details of the settlement were not disclosed.

In January 1989, Motorola filed a lawsuit against Hitachi charging patent infringement and unfair competition that Motorola claimed began after it granted Hitachi a patent license for certain devices in 1986. Motorola's position was that Hitachi's new H8 microcontroller series infringed on at least four Motorola patents. Approximately one week after Motorola's charges, Hitachi responded by filing a patent infringement suit against Motorola. Hitachi alleged infringement of one of its patents by Motorola's 68HC11 8-bit microcontroller and countered that not only did its H8 not infringe on any Motorola patent, but that the device was covered by a patent license. In June, Hitachi filed an amendment to its pending lawsuit against Motorola to include allegations of patent infringement by Motorola's 68030 microprocessor.

On March 29, 1990, in a US district court in Austin, Texas, Federal Judge Lucius Bunton decided that Hitachi's H8 microcontroller was not licensed under the parties' 1986 Patent License Agreement; consequently, Hitachi committed patent infringement on three of Motorola's patents. Hitachi, therefore, was ordered to cease selling the H8 for the life of the affected patents and to compensate Motorola in the amount of $1.9 million. The judge also ruled, however, that Motorola infringed on an Hitachi patent and therefore was barred from marketing or selling its 68030 microprocessor for the duration of the patent; Motorola thus was required to pay Hitachi

Table 3-2

SEMATECH External Development Contracts
May 1989 to April 1990

Contract Date	Contract Partner	Program Type	Technology Focus
May 1989	ATEQ	JDP	Submicron reticle and mask exposure system
May 1989	GCA	EIP	I-line steppers
May 1989	GCA	JDP	Optical wafer stepper
May 1989	HP	JDP	Test chips
May 1989	Westech Systems	JDP	Global planarization processes
May 1989	SemiGas Systems	JDP	Ultrapure gas management systems
May 1989	Union Carbide	JDP	Ultrapure gas management systems
May 1989	Wilson Oxygen	JDP	Ultrapure gas management systems
July 1989	Eaton	JDP	Sputtering cluster tool
August 1989	NCR	JDP	Advanced isolation
August 1989	Nat'l. Inst. of Standards and Tech.	JDP	Metrology standards
Sept 1989	Sandia Nat'l. Lab	TAA	Establishment of Semiconductor Equipment Technology Center (SETEC)
Nov. 1989	Lam Research	EIP	Metal etch systems
Dec. 1989	Texas State Tech. Inst./ Center for Occupational Research and Development	TAA	Manufacturing specialist training program
Dec. 1989	Silicon Valley Group	JDP	Advanced photoresist processing
Dec. 1989	KLA	JDP	Wafer defect detection
Dec. 1989	ORASIS	JDP	Wafer defect detection
Dec. 1989	Oak Ridge Nat'l. Lab	TAA	plasma etch technology
Jan. 1990	Angstrom Measurements	EIP	Critical dimension measurement systems
Jan. 1990	Lam Research	JDP	Electron cyclotron resonance (ECR) CVD
Jan. 1990	University of Cincinnati	JDP	Plasma etch technology
Jan. 1990	ASTeX	JDP	Plasma etch technology
Feb. 1990	Ion Implant Services/Genus	TAA	High-energy implantation technology
Mar. 1990	Hampshire	JDP	Soft X-ray lithography
Mar. 1990	Drytek	JDP	Low-temperature plasma etch
April 1990	Applied	EIP	Dielectric CVD

JDP—Joint Development Project
EIP—Equipment Improvement Project
TAA—Technical Assistance Agreement
Source: Dataquest (August 1990)

$500,000 in damages. Following the decision, the judge quickly granted Motorola's request for a stay of the injunction on the 68030. At this point, both parties have the option of appealing the decision or negotiating a settlement.

A number of other lawsuits were filed in the industry in 1989 and early 1990. Although none of these cases has received the media attention that was given to the aforementioned cases, they are equally significant as semiconductor vendors struggle to protect their intellectual property and market share. In May 1989, AMD charged that two patents recently issued to Brooktree Corporation for digital-to-analog converter functions are not inventions within the meaning of US patent laws. AMD's effort to invalidate the Brooktree patents is the latest development in a litigation process that has continued since 1988. The dispute concerns color palette ICs produced by the two companies. Brooktree claims that AMD's devices infringe on its mask works, but was denied a restraining order against AMD following a hearing in November 1988.

In October, National Semiconductor announced that a patent infringement suit filed in 1985 against Linear Technology had been settled. The suit claimed that Linear had infringed on ten National patents, all related to analog products. Under the terms of the settlement, Linear has agreed to pay $3 million in return for irrevocable licenses, releases, and a comprehensive ten-year binding arbitration agreement. The case had just gone to trial in March 1989 when an opportunity arose to settle the case on mutually acceptable terms.

SGS-Thomson began 1990 with two new lawsuits against Dallas Semiconductor and Hyundai. In January, SGS-Thomson announced that it had filed a patent infringement suit against Dallas Semiconductor. At issue is the alleged infringement of SGS-Thomson's patents pertaining to battery-backed memory devices. License discussions between the two companies had recently broken down. In February, SGS-Thomson brought suit against Hyundai for patent infringement against SGS-Thomson's patents on DRAMs and SRAMs. The company had tried unsuccessfully for 18 months to conclude a licensing agreement that would provide compensation for Hyundai's use of SGS-Thomson's intellectual property.

Two other suits have been filed by Intel as the company tries to protect its market share in the floating-point coprocessor market. In February 1989, Intel filed suit against ULSI System Technology for developing products that substitute for Intel's 80387 math coprocessor through the "theft and misuse of Intel's proprietary information" pertaining to the 80386 microprocessor, the 80387 coprocessor, and Intel's i80860 64-bit microprocessor. Also, in April 1990, Intel filed a complaint against AMD, claiming that AMD has infringed on microcode copyrights on the Intel 80287 math coprocessor. Intel's action followed a notice by AMD stating that they have incorporated the Intel microcode into a coprocessor that AMD plans to announce soon.

A list of notable 1989 and 1990 lawsuits appears in Table 3-3.

Table 3-3

Litigation: 1989-1990

Plaintiff	Defendant	Date Filed	Subject	Resolved?
Intel	NEC	1984	MPU code	Yes
National	Linear Tech.	1985	Analog patents	Yes
International Rectifier	Siliconix	7/86	Patents: MOSFETs	Yes
Motorola	Hitachi	1/89	Patent: MCUs	No
Hitachi	Motorola	1/89	Patent: MCUs	No
Gazelle	AMD	1/89	Patent fraud: PLDs	No
Intel	ULSI System Technology	2/89	Coprocessors	Yes
AMD	Brooktree	5/90	DAC patents	No
Atmel	AMD SEEQ	1/90	Patent: circuitry	No
Chips	Elite Microelectronics	1/90	Trade secrets, breach of contract	No
SGS-Thomson	Dallas Semiconductor	1/90	Patent: battery-backed memories	No
SGS-Thomson	Hyundai	3/90	Patent: memories	No
AMD	Samsung		Patent: PLDs	Yes
Intel	AMD	4/90	Coprocessor code	No

Source: Dataquest (August 1990)

International Trade

The subject of international trade continued to be a hot topic in 1989. The Omnibus Trade Act and the US-Japan Semiconductor Trade Arrangement of 1986 served as the basis for most discussion surrounding international trade. Super 301 is a provision of the 1988 Omnibus Trade Act passed by the US Congress. According to this provision, the US Trade Representative (USTR) must identify "priority countries" and "priority practices" that inhibit US trade in world markets and then take actions against those countries and practices. Many observers, including the SIA, speculated that Japan would be placed on the list of Super 301 offenders for its practices in the semiconductor industry. On May 25, 1989, USTR Carla Hills put an end to speculation about Japan's inclusion on the "Super 301" list for semiconductor trade practices. Although Japan will be investigated under US trade law for committing "priority practices" (i.e., trade barrier erection) in connection with telecommunications satellites and supercomputers, semiconductors will not be a subject of the USTR's investigative focus.

The main focus of the relationship between the United States and Japan relates to the US-Japan Semiconductor Trade arrangement. To date, much of the furor over the implementation of the Arrangement has centered on the issue of measuring market access—and this issue has in turn centered on the interpretation of the now infamous "side letter," dated September 1, 1986, between Ambassador Matsunaga of Japan and Ambassador Yeutter of the United States. One particularly controversial section of the letter reads:

> "The Government of Japan recognizes the US semiconductor industry's expectation that semiconductor sales in Japan of foreign capital-affiliated companies will grow to at least slightly above 20 percent of the Japanese market in five years. The Government of Japan considers that this can be realized and welcomes its realization. The attainment of such an expectation depends on competitive factors, the sales efforts of the foreign capital-affiliated companies, the purchasing efforts of the semiconductor users in Japan, and the efforts of both Governments."

The attainment of 20 percent market share by 1991 has become the de facto measure of Japan's success in opening its markets. In April 1989, Japan's Ministry of International Trade and Industry (MITI) introduced an 11-point, step-by-step plan to solve the US complaint of closed markets. MITI's 11-point plan includes the following provisions:

- MITI will encourage major semiconductor users, including Electronic Industry Association of Japan (EIAJ) users' committee members and Japan Auto Parts Industries Association (JAPIAS) members, to adopt market access plans.
- MITI will encourage expansion of efforts to design-in foreign semiconductors.
- MITI will encourage Japanese manufacturers of consumer electronics to do joint developments with foreign semiconductor suppliers, the objective of which is to increase the foreign semiconductor content in consumer electronics.
- MITI will encourage ISDN equipment makers to aim programs at design-ins of foreign semiconductors.

The success of MITI's efforts thus far is questionable. Andrew Procassini, president of the Semiconductor Industry Associate (SIA), has praised the five largest Japanese semiconductor consumers for increasing their purchases of semiconductors to 17 percent of total supply from foreign suppliers. Dataquest notes that the other Japanese companies procure only about 7 to 8 percent of their semiconductor needs from foreign sources. US and Japan-based market share estimates tend to diverge greatly. In April 1990, the International Semiconductor Cooperation Center (INSEC) announced that a survey conducted to identify the progress of the Japanese market access for foreign-made ICs indicated that the average purchase of foreign-made ICs by 53 users that responded was 12.9 percent. However, Dataquest estimates that foreign ICs accounted for only 10.0 percent of Japanese IC consumption in 1989.

Despite these conflicting claims, we have observed significant effort on the part of some Japanese manufacturers to increase the market share of foreign-made ICs in Japan. In addressing US criticism regarding the inaccessibility of its marketplace, Japan is directing much of its efforts toward responding to this issue through the vehicle of alliances so that greater market access can be achieved via these measures. In March 1989, AT&T and NEC announced an agreement whereby AT&T will obtain a license to design, manufacture, and market NEC's gate array products. Under this agreement, NEC and other Japanese companies will be able to boost their purchases of foreign semiconductors. In another recent agreement, Kobe Steel and TI announced the establishment of a joint venture in Japan to manufacture VLSI ICs and ASICs, which will be sold through TI. In addition, a number of other strategic alliances were formed between US and Japanese companies in 1989. For more details, refer to the subsection entitled "Alliances."

Although most discussion of trade was dominated by US/Japan topics, several developments in Europe also made headlines. In March 1989, the European Economic Community (EEC) announced that it planned to increase the duty rate paid by foreign manufacturers of 256K DRAMs from 10 to 14 percent. The EEC explained that because NEC and Siemens are now producing significant quantities of 256K DRAMs in Europe, the EEC is justified in raising the import duty to the full 14 percent. In February 1990, after months of speculation, the EC announced that an agreement had been reached between itself and the 11 Japanese vendors that sell into Europe. Under the terms of the agreement, a price floor was established for all densities of DRAMs; suppliers cannot legally sell below this floor without facing dumping charges. Although the reference price is not publicly known, it is based on cost, a capital and R&D expenditure allowance, a selling, general, and administrative (SG&A) expense margin and a profit margin of 9.5 percent.

Another European issue that remained at the forefront of international discussions is the scheduled 1992 unification of Europe, with the dropping of inter-Europe trade barriers. Realizing the immense size of a unified European market, many large Japanese and US semiconductor manufacturers continued to invest heavily in European manufacturing facilities in 1989 in order to avoid import duties by producing semiconductors locally.

Alliances

In 1989 and early 1990, a number of strategic alliances were formed between US and Japanese companies. Some of these alliances involved start-ups looking to Japanese vendors for manufacturing capacity for their new products. For example, VIA Technologies has teamed up with Fujitsu to jointly develop chip sets for Sun-compatible workstations. Ramtron signed a joint development agreement with Seiko-Epson under which Seiko-Epson will provide Ramtron with manufacturing capacity for ferroelectric memory products developed jointly with Ramtron. In November, Vitesse signed an agreement with Fujitsu whereby Fujitsu will second-source GaAs ASICs developed by Vitesse. In January 1990, Actel signed a manufacturing agreement with Matsushita that allows Matsushita to manufacture ASIC products for Actel. In February, Echelon formed an alliance with Motorola and Toshiba whereby the two companies will manufacture and distribute semiconductors developed by Echelon. Also in February, Kubota, a Japanese machinery manufacturer, signed an agreement with C-Cube Microsystems to codevelop image-processing ICs.

In addition to these alliances between start-ups and Japanese suppliers, several alliances occurred between major US and Japanese semiconductor manufacturers. In May 1989, Motorola agreed to second-source Toshiba's new 74BC BiCMOS logic family. In July, Hitachi and Texas Instruments agreed to mutually second-source each other's SRAMs. In August, HP licensed its RISC-based Precision Architecture along with its advanced submicron CMOS process technology to Samsung. In January 1990, NMB Semiconductor signed an agreement with Intel whereby NMBS will manufacture DRAMs for sale by Intel. In March, AT&T and NEC announced an agreement under which AT&T will be licensed to design, manufacture, and market NEC's gate array products. In return, NEC will receive AT&T's sophisticated CAD tools for ASICs. The relationship also called for AT&T to provide manufacturing support for NEC's 4-bit microcontrollers.

In recent years, there has been an observable trend among Japanese steel and heavy industry companies toward diversification into the electronics industry. In 1985, Kawasaki Steel formed Nihon Semiconductor, a joint venture with LSI Logic Corporation. In the past year, we have seen two new alliances between Japanese heavy industry companies and US semiconductor companies. One, which was mentioned earlier, is the alliance between Kubota and C-Cube to jointly develop image compression ICs. In March 1990, Kobe Steel of Japan announced a joint venture with Texas Instruments to manufacture VLSI ICs and ASICs. Table 3-4 provides a list of alliances in 1989 and early 1990.

Table 3-4

Alliances: 1989-1990

Company 1	Company 2		Date	ProductType
Samsung	NCR	January 1989	ASICs, SRAMs	Cross-license
AT&T	Intel	January 1989	Communication ICs	Product & technology exchange
Logic Devices	AT&T	January 1989	SRAMs	Foundry
TI	Acer	February 1989	DRAMs	Joint manufacturing
Fujitsu	VIA Technologies	March 1989	Chip sets	Joint development
Intel	IBM	March 1989	DVI	Joint development
ACC Micro.	Motorola	April 1989	Chip sets	Second-source
Ramtron	Seiko-Epson	April 1989	Ferroelectric memory	Joint development
Sanyo	Mosaid	April 1989	DRAMs	Joint development
Toshiba	Siemens	May 1989	ASICs	Second-source
AMD	Lattice	May 1989	PLDs	Cross-license
Motorola	Toshiba	May 1989	BiCMOS logic	Second-source
Simtek	Plessey	July 1989	EPROMs	Licensing
Hitachi	Goldstar	July 1989	DRAMs	Licensing
Hitachi	TI	July 1989	SRAMs	Joint supply
AMD	ICT	July 1989	EPROMs	Joint development
HP	Samsung	August 1989	RISC	Licensing
AT&T	Paradigm	August 1989	SRAMs	Joint development
SEEQ	Philips-Signetics	October 1989	Flash, EEPROM	Foundry, licensing
Fujitsu	Vitesse	November 1989	GaAs ASICs	Second-source
AT&T	Xilinx	December 1989	ASICs	Manufacturing
Toshiba	Int'l. Rectifier	December 1989	MOSFETs	Licensing
Samsung	Intergraph	December 1989	Clipper MPUs	Licensing
Intel	VLSI	January 1990	Chip sets	Remarketing
National	Acer	January 1990	Micros	Joint development
Intel	NMB	January 1990	DRAMs	Marketing
Siemens	IBM	January 1990	DRAMs	Joint development
Actel	Matsushita	January 1990	ASICs	Manufacturing, marketing
IBM	Siemens	February 1990	DRAMs	Joint development
AT&T	Mitsubishi	February 1990	SRAMs	Manufacturing, marketing, technology sharing
Echelon	Motorola Toshiba	February 1990	LON ICs	Manufacturing
C-Cube	Kubota	February 1990	Image compression	Joint development
AT&T	NEC	March 1990	ASICs, MCUs	Manufacturing, marketing
SGS-Thomson	Siemens	March 1990	MCUs	Second-source
SGS-Thomson	Oki	March 1990	DRAMs	Joint manufacturing
TI	Kobe Steel	March 1990	ASICs	Joint venture
LSI	Hyundai, Metaflow	March 1990	SPARCs	Joint development
Actel	HP	April 1990	ASICs	Joint development
AMD	Vitesse	May 1990	GaAs communication ICs	Joint development
Intel	TSMC	May 1990	DRAMs	Manufacturing

Source: Dataquest (August 1990)

Mergers and Acquisitions

A significant amount of merger and acquisition activity occurred in 1989. An increase in such activity often occurs in periods of industry slowdowns and following periods of extensive start-up activity. Historically, Dataquest has identified a period of consolidation, acquisition, and a shakeout of start-ups following each peak of start-up activity. Although the number of start-ups has recently been declining, the number of mergers, acquisitions, and closures has increased in the last two years. In 1989, four start-ups were acquired by larger companies. Silicon Systems was acquired by TDK; Inmos, the British memory and microprocessor manufacturer, was acquired by SGS-Thomson; Mietec, a Belgian ASIC supplier, was acquired by Alcatel; and Krysalis, a ferroelectric memory start-up, was acquired by National Semiconductor. In addition, LSI Logic merged two of its recent acquisitions, G-2 and Video Seven, to form Headland Technology, a subsidiary of LSI that manufactures PC logic and graphic chip sets.

In addition to these acquisitions of start-ups, a number of other significant acquisitions occurred in 1989 and early 1990. A number of these acquisitions also involved start-ups, as these small companies attempted to gain manufacturing capacity and diversify their product lines. In April 1989, the ASEA Brown Boveri Power Semiconductor Division was acquired by IXYS, a start-up discrete semiconductor manufacturer. In June, the management and employees of Zilog purchased the company from its parent, Exxon, with funding from Warburg, Pincus Capital Company. Also in June, Atmel, a nonvolatile memory start-up, purchased Honeywell's Solid State Electronics division in Colorado Springs, Colorado. Included in the purchase were three wafer fabs plus related assembly, testing, and engineering facilities. General Electric Microelectronics was acquired by Harris in July. In January 1990, Atmel acquired Westinghouse's Chesapeake ASIC design group. In February, Vitelic acquired Elcap Electronics Limited, one of Hong Kong's pioneers in wafer fabrication. In doing so, Vitelic, a start-up memory manufacturer, acquired a 69,000-square-foot wafer fab, which the company will upgrade to a 5-inch submicron production facility.

A list of 1989 and 1990 acquisitions of semiconductor companies is found in Table 3-5.

Semiconductor Megatrends in the 1990s

The following list contains Dataquest's predictions for semiconductor megatrends in the 1990s:

- Economic power will displace military power.
- Closeness to the customer will be an imperative.
- Electronics will pervade all aspects of society.
- Technological obsolescences will increase.
- Consolidation and retrenchment will become the norm.

Table 3-5

Mergers and Acquisitions: 1989-1990

Acquired Company	Acquired By	Date	Product Area
Inmos	SGS-Thomson	March 1989	Transputers, SRAMs, DSP, graphics
G-2	Video Seven*	April 1989	Chip sets
Silicon Systems	TDK	April 1989	ASICs
ABB Power Semi.	IXYS	April 1989	Discretes
Zilog	Employees	June 1989	Microcomponents
Honeywell	Atmel	June 1989	NV memory
GE Micro	Harris	July 1989	ASICs
Krysalis	National	October 1989	NV memory
Mietec	Alcatel	November 1989	Telecom chips
Chesapeake Group	Atmel	January 1990	ASICs
Elcap Electronics	Vitelic	February 1990	Memory

*Now Headland
Source: Dataquest (August 1990)

- Southeast Asia's growth will lead the decade.
- The industry's capital intensity will grow.
- Partnerships will become standard business practice.
- Software will be the king of the '90s.
- Japan will have peaked in growth and the United States will have bottomed out.

Economic Power Will Displace Military Power

We believe that economic power will displace military power as the basis for worldwide dominance. Countries will shift their focus away from military spending and concentrate on strategies to create economic might. Electronic and information transfer industries will be viewed as essential to establishing economic power. Global trade policies will become the new battleground as entities throughout the world seek to protect or enhance their individual economic strengths. Companies that cannot compete on a global basis will realize growth rates and financial returns that are substantially less than industry averages.

Closeness with Customers Will Be an Imperative

Region-based manufacturing should become an imperative of the next decade, as will an entirely new level of service. Driven by trade laws, local content requirements, and the new strategy of establishing factories close to the point of consumption, partnerships such as the Acer/Texas Instruments consortium to produce DRAMs for the Taiwanese market will become commonplace. This fact will hold true for the manufacture of electronic equipment as well as components. Japanese companies already have begun to establish substantial manufacturing capabilities in the United States, and both US and Japanese companies are moving en masse into Europe with IC production factories. Product and price differentiation will be difficult; hence, service will become a new and powerful marketing tool.

Electronics Will Pervade All Aspects of Society

Electronics will become ubiquitous—a common denominator throughout all levels of society. Consumer electronics (with emphasis on personal use) that are perceived to enhance one's life or offer opportunities for saving time will be key drivers during the early portion of the next decade. We see widespread consumption of ISDN-driven products, personal cellular telephones, home fax machines, home copiers and laser printers, and home automation products, as well as personal entertainment systems. This bodes well for analog products as well as for mixed-signal and conventional digital devices. We do not see HDTV as having significant impact on either consumers or IC producers until very late in the decade.

Technological Obsolescences Will Increase

We predict that technological obsolescences will occur at an even faster rate during the '90s than in the '80s. Product life cycles, despite increasing product complexity, will be shorter than in the past decade. Innovation, driven by astounding leaps in software technology and the information transfer industry, will place immense pressures on product survivability. Developing a product that can capture market leadership long enough to recover the investment cost of development will become a key challenge.

Consolidation and Retrenchment Will Become the Norm

The European, US, and Japanese semiconductor industries are expected to reach full maturation in the 1990s. Annual growth rates will more closely follow those of traditional mature industries such as automobiles. Substantial consolidation will take place in the US semiconductor industry, resulting in only a few, very large US semiconductor producers by the end of the decade. Niche market players will become increasingly rare, finding that their markets of choice are too small to allow for annual research and development investments that are commensurate with industry averages. A shakeout will occur among the Japanese device producers as a result of too many participants entering the IC market from nontraditional sourcessuch as the Japanese steel, chemical, and heavy industry companies. The majority of the retrenchments will come from ASIC entities that lack substantial vertical integration capabilities.

Southeast Asian Growth Will Lead the Decade

Southeast Asia will be the region exhibiting the greatest growth and the largest number of new IC ventures. Dataquest predicts that Thailand will become the fifth tiger. Virtually all of the newly industrialized countries (NICs) will adopt the strategy that an indigenous semiconductor industry is essential to the development of a modern economy. The proliferation of ASIC design tools will enhance this region's goal of becoming independent of both Japan and the United States for the supply of complex ICs. India will become an important electronic equipment consumer and semiconductor device producer. The Eastern Bloc and Soviet countries will become significant electronic equipment consumers toward the end of the decade as they realize the necessity of establishing economic rather than military power. China will be neither a significant consumer nor producer of semiconductors. Despite current rhetoric that China's modernization program still is top priority, the impact of the June 1989 events in Beijing will most likely continue well into the next decade.

The Industry's Capital Intensity Will Grow

Dataquest foresees that the capital intensity of the industry will grow. Companies no longer will be able to use DRAMs as their sole process drivers. DRAM technology will pace lithography and three-dimensional events (trench capacitors); however, ASIC technology will set the cadence for multiple levels of interconnections, deposited films, and packaging developments. Consequently, broad market participants will have to make significant investments in both DRAM and ASIC technologies. Wafer fabrication facilities will become product-focused rather than process-focused. Operations will be built principally for the lifetime of one specific product (e.g., factories for 16Mb, 64Mb, and 256Mb products), with possible later-stage revamping for less demanding technologies. This scenario favors commodity memory producers over ASIC and analog producers for the greatest leverage of wafer fabrication capital investment.

Partnerships Will Become Standard Business Practice

Partnerships and technology transfer are likely to become key strategies in the next decade. The staggering cost of technology will be only a portion of the problem to be solved. As product lifetimes decrease, the time to market for products will become predominant. Even a minor setback in product development could translate to missing an entire product cycle, recovery from which may be impossible. Partners not only will share the cost of the technology but also the task of getting the product to market in time to minimize the risk of lost opportunity. The NICs will look to the established countries for technology. This know-how will be exchanged for local market access and assistance in establishing regional manufacturing capability. Companies that lack partnering skills or cannot leverage their technology will suffer against their more adept global competitors.

Software Will Be the King of the '90s

As software standards become pervasive, hardware will become a commodity item. We predict that the Silicon Valley will realize an era of venture capital-backed software start-up companies that will rival the IC company start-up era of the '70s.

Japan Will Have Peaked in Growth; the United States Will Have Bottomed Out

Dataquest anticipates that Japan's amazing growth rate will peak very early in the decade. As the Japanese accept their position as the most wealthy people on earth, they will begin to enjoy the fruits of their efforts and lessen their obsession with economic survival. The younger Japanese generation, having never known the hardships of their elders, will be unwilling to make the same sacrifices of unquestioned long work hours, blind devotion to corporate goals, and lack of personal identity. This phenomenon is not unique to the Japanese, but rather a continuing enactment of the drama that has occurred in every highly successful emerging nation including Ming China, the Ottoman Empire, the countries of Western Europe, Great Britain, and the United States. The United States has bottomed out in its descent and now is finally addressing the decline in global competitiveness, deteriorating industries, poor product quality, the drug problem, and the seeming inability to create products that its citizens will buy. We believe that by the end of the century, Japan and the United States will be virtually at parity; however, Japan still will be slightly in the lead. Both nations will have shouldered many of the world's problems and will unite in their mutual anxiety over the ever-growing economic strength of Southeast Asia.

CHAPTER 4

Electronic Equipment Segment of the Economy

Introduction

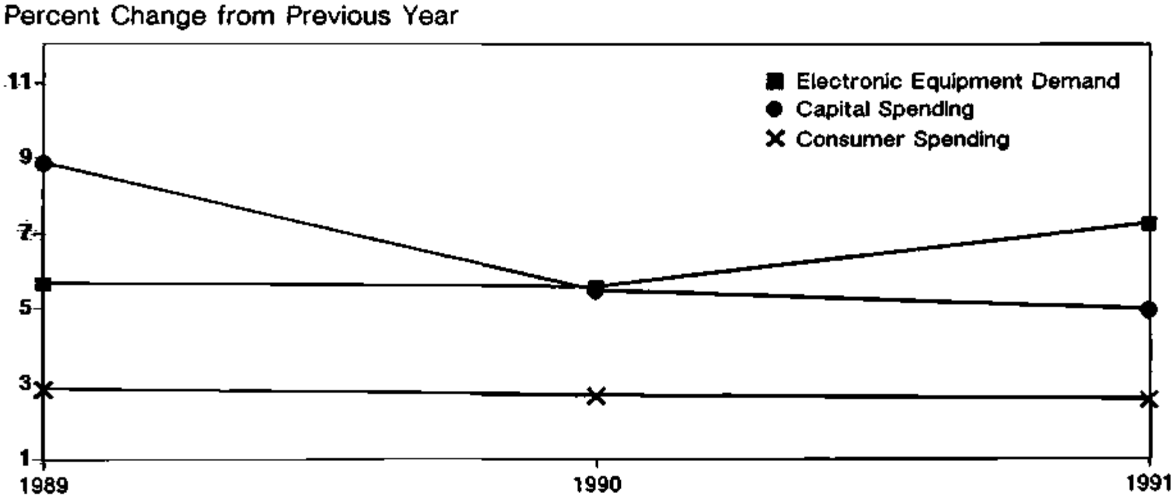
The steadily growing electronic equipment segment of the global economy is a major contributor to worldwide economic growth. Dataquest estimates that 1988 worldwide electronic equipment sales accounted for nearly 8 percent of OECD members' output of goods and services. In 1989, that amounted to $653 billion out of $10 trillion, measured in current US dollars. Illustrative of this growth and contribution is the fact that electronic equipment progressed from less than 3 percent of the OECD output in the mid-1970s to just shy of 5 percent in 1984 to nearly 8 percent in 1988.

Chapter 3 developed the headwaters of the waterfall of demand and established that the global economy has been expanding vigorously since 1987. The major force behind this recent worldwide economic expansion has been spending related to private, fixed, nonresidential investments (capital spending by businesses), as shown in Figure 4-1.

Although worldwide consumer spending has declined considerably as an economic driving force from its 1985 historic levels of more than 5 percent annual growth, it has been on the rise in some regions during the past two years. This increase has occurred in countries that have enjoyed recent buoyant economic growth—Japan, Asian NICs, the United Kingdom, and West Germany. Although Japanese and Asia/ROW consumer spending has been less than that of the United Kingdom or West Germany, it has not been an insignificant contributor to worldwide electronic equipment growth, as shown in Figure 4-1.

Figure 4-1

Worldwide Electronic Equipment Demand versus Capital and Consumer Spending 1989-1991 Annual Growth



Source: Dataquest (August 1990)

Because the electronic equipment industry sells products in all three economic sectors—private business, consumer, and government—the industry has been able to take advantage of the growth in consumer and capital spending. It therefore has enjoyed moderate growth worldwide over the last two years. Dataquest estimates that annual growth for electronic equipment exceeded 16 percent in 1988, whereas 1989 growth was substantial but slower—approximately 6 percent (see Figure 4-1).

This chapter takes the first step down the waterfall of demand. In the process, it develops the following three important topics:

- Demand for electronic equipment—This includes a discussion of worldwide and regional economic demand drivers.
- Production of electronic equipment—Key regional economic and competitive issues discussed in Chapter 3 are used to relate worldwide demand to worldwide and regional forecasts of electronic equipment production.
- Procurement of semiconductor devices—Regional electronic equipment production forecasts are used to generate regional forecasts of semiconductor expenditures for 1989 and 1990. This is addressed as a strategic issue within the section entitled "Electronic Equipment Production."

Electronic Equipment Demand

This section on electronic equipment demand provides the following information:

- Background for electronic equipment demand
- Electronic equipment demand forecast for 1990 and 1991
- Strategic issues regarding the electronic equipment demand forecast

Background

The background information for electronic equipment demand explores the following areas:

- Equipment market segments—What is included in the electronic equipment market?
- Market segment growth—What is driving equipment market growth?
- Sources of demand—Who buys electronic equipment?
- Regional equipment demand—Where is electronic equipment purchased?

Equipment Market Segments

Dataquest segments the electronics industry into six major application markets, defined as follows:

- Data processing
- Consumer
- Industrial
- Communications
- Military
- Transportation

Data Processing

Data processing comprises all equipment that functions as information processors, including all personal computers, regardless of price or the environment in which they are used. About 10 percent of this segment's equipment is assumed to be purchased by the consumer sector of the economy. The balance (90 percent) is purchased by the private business and government sectors.

Consumer

The consumer segment comprises equipment that is used primarily in the home for personal use, such as audio and video equipment and household appliances. All equipment in this segment is purchased by the consumer sector of the economy.

Industrial

The industrial segment consists of all manufacturing-related equipment, including scientific, medical, and dedicated systems. It is assumed that all equipment in this segment is purchased by the capital spending sector of the economy.

Communications

Most of the communications segment is made up of telecommunications equipment, which Dataquest classifies as customer-premises and public telecommunications equipment, and all other communications equipment, such as radio transmission, studio, and broadcast equipment. All of the equipment in this sector is assumed to be purchased by either the capital spending or government purchasing sectors of the economy.

Military

Military equipment is primarily defense-oriented electronic equipment and thus does not include all electronic equipment procured by the government. In order to avoid double-counting, equipment that belongs in an already defined application market segment is not included here. All equipment in this segment is purchased by the government (defense) spending sector of the economy.

Transportation

Transportation consists mainly of automotive and light-truck electronics. All equipment in this segment is assumed to be purchased by the consumer sector of the economy.

Market Segment Growth

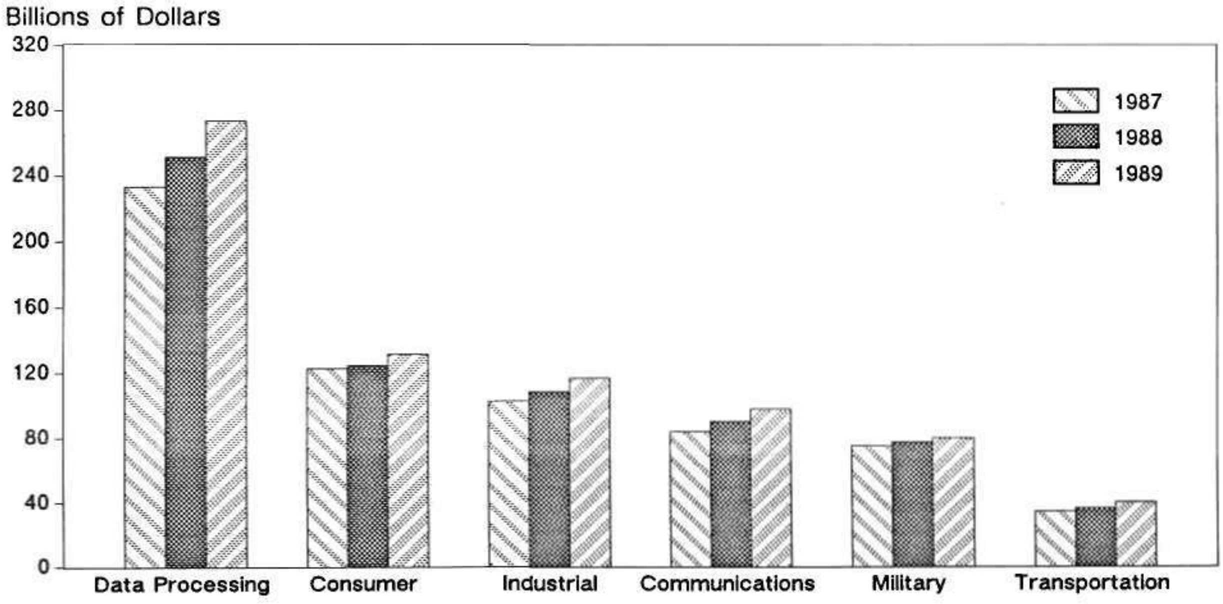
The worldwide electronics industry production growth by application market is illustrated in Figure 4-2. Growth was driven primarily by the data processing and consumer markets. Figure 4-3 shows that although production share of these two segments grew onlyt slightly from 54.0 percent to 54.5 percent from 1987 to 1989, these two market segments still represent a majority of worldwide equipment production and semiconductor demand. At the same time, production share of the industrial market has grown from 14.2 to 15.8 percent over that same period, while the production share for the military segment has dropped from 13.7 percent to 11.6 percent.

Major growth products within the data processing and consumer markets have been personal computers, workstations, storage peripherals, terminals, personal printers, VCRs, and compact disc players. These growth products have the following common attributes:

- High semiconductor content
- High unit volume
- Large market (All of these products are used by individuals and thus are assured of a large total available market.)

Figure 4-2

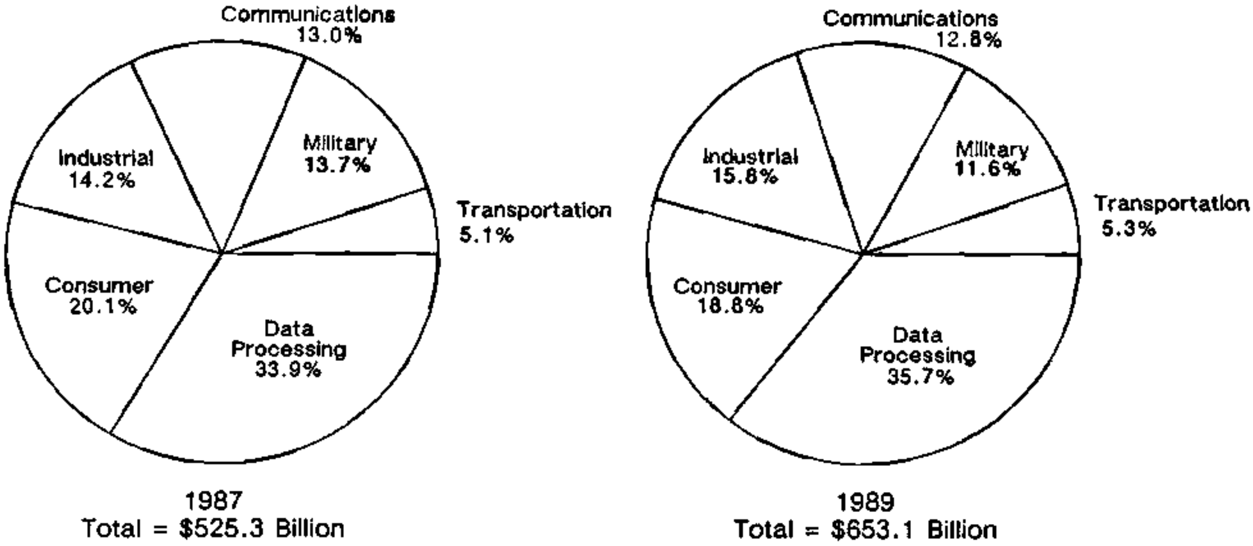
Worldwide Electronic Equipment Market Growth by Application Market Segment—1987-1989



Source: Dataquest (August 1990)

Figure 4-3

Worldwide Electronic Equipment Production Share by Application Market Segment—1987 and 1989



Source: Dataquest (August 1990)

Demand Sources

The growth in worldwide demand for electronic equipment is determined by the growth in worldwide spending from the following three major economic sectors:

- Private, fixed, nonresidential investments (otherwise known as capital spending)
- Consumer spending
- Government spending

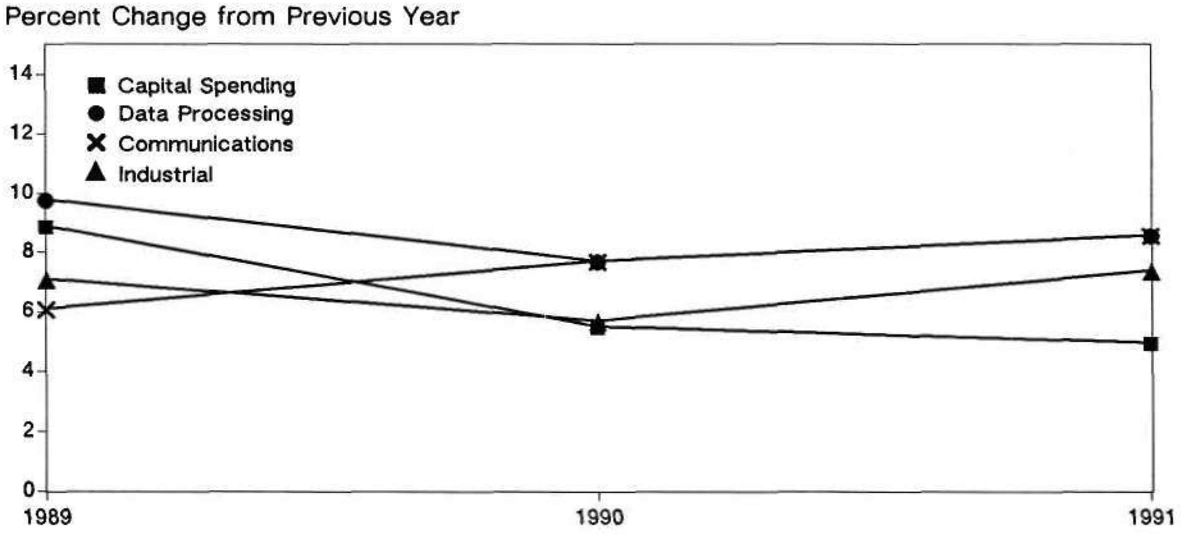
It is important to note that, in terms of demand growth, individual market segment growth is a function of the growth of the economic sectors in which major purchases occur. For example, the data processing, industrial, and communications segments are purchased mostly by the capital spending sector and represent nearly 60 percent of total equipment demand. The consumer and transportation segments are purchased mostly by the consumer sector and represent approximately 30 percent of total demand. All of the military segment is purchased by public sector and represents 10 percent of the total equipment demand. Supply issues, on the other hand, tend to be more global in nature. The growth of the equipment demand as a whole therefore is determined by the growth rates of the individual economic sectors weighted by the relative size of each sector, as well as supply-side issues such as price and technology.

Additionally, it is important to note that small percentage changes in sector spending can have a big impact on equipment demand due to the size of the consumer spending sector. Any change in capital spending has a direct and significant impact on equipment demand, particularly in the data processing, communications, or industrial segments (see Figure 4-4). Furthermore, as Figure 4-5 shows, consumer and transportation segments are tied to the consumer spending sector. The consumer spending sector has been flat and is forecast to continue the same pattern, but the consumer equipment and transportation segments have experienced dynamic growth swings resulting from relatively small changes in consumer spending.

As a historical example of how economic sector spending influences electronic equipment demand, consider the 1985 and 1986 near-recession in the United States. Through 1983 and 1984, the US economy was enjoying a consumer-driven shopping spree. This spree stimulated North American capital spending, as companies in all segments of the economy scrambled to increase capacity and productivity to participate in the boom. The high value of the dollar drove import prices well below those of domestic products, and Japan, the Asia/ROW countries, and West Germany were the major benefactors from all this spending. Figure 4-6 illustrates actual and forecast worldwide and regional consumer spending growth rates for the 1986 to 1991 period.

Figure 4-4

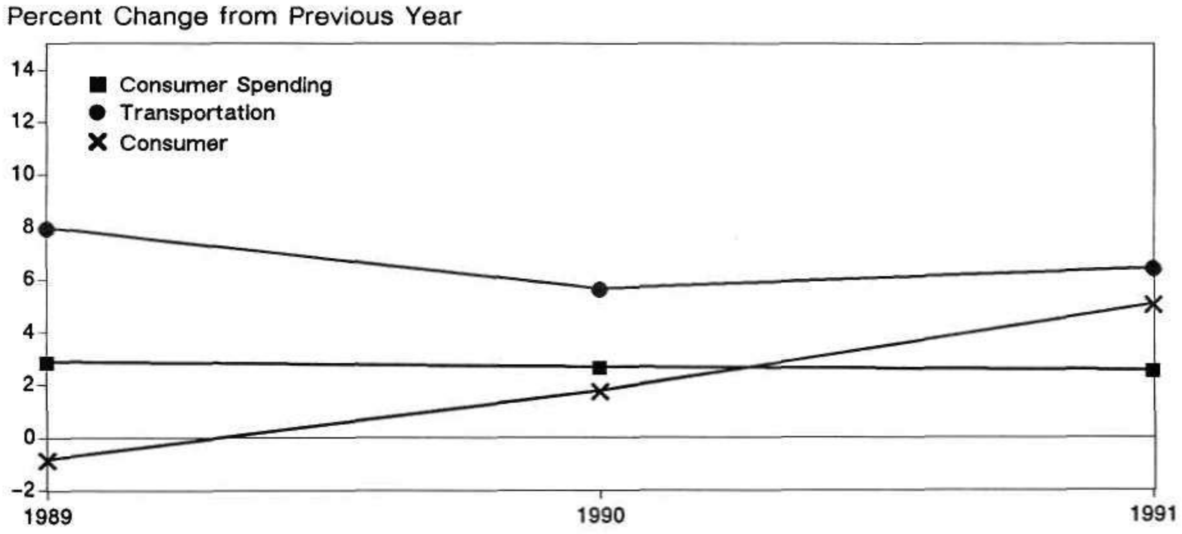
Worldwide Electronic Equipment Demand and Capital Spending by Application Market—1989-1991



Source: Dataquest (August 1990)

Figure 4-5

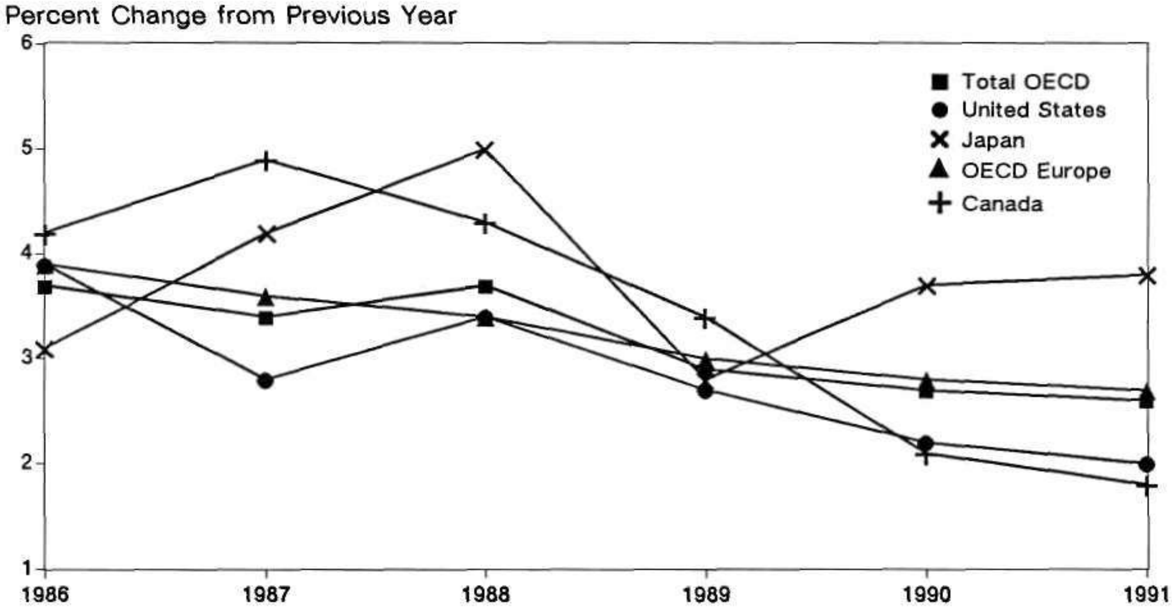
Worldwide Electronic Equipment Demand by Application Market—1989-1991



Source: Dataquest (August 1990)

Figure 4-6

Actual and Forecast Worldwide and Regional Consumer Spending—1986-1991



Source: Dataquest (August 1990)

By 1985, the strength of the dollar had all but choked US exports. Rapidly rising interest rates that were due to the high demand for funds to finance all the deficit spending stalled capital spending growth as well.

However, from 1986 through mid-1989, North American equipment demand was buoyant, aided by increasing growth rates of North American capital spending (see Figure 4-7). Growth in electronic equipment demand is expected to be moderate through 1991, as the worldwide economy remains relatively soft. US capital spending fell 3.3 percent in 1986 before rebounding 3.9 percent in 1987 and 8.4 percent in 1988, which is shown in Figure 4-7.

Regional Equipment Demand

The regional equipment demand forecasts provided are based on the following assumptions:

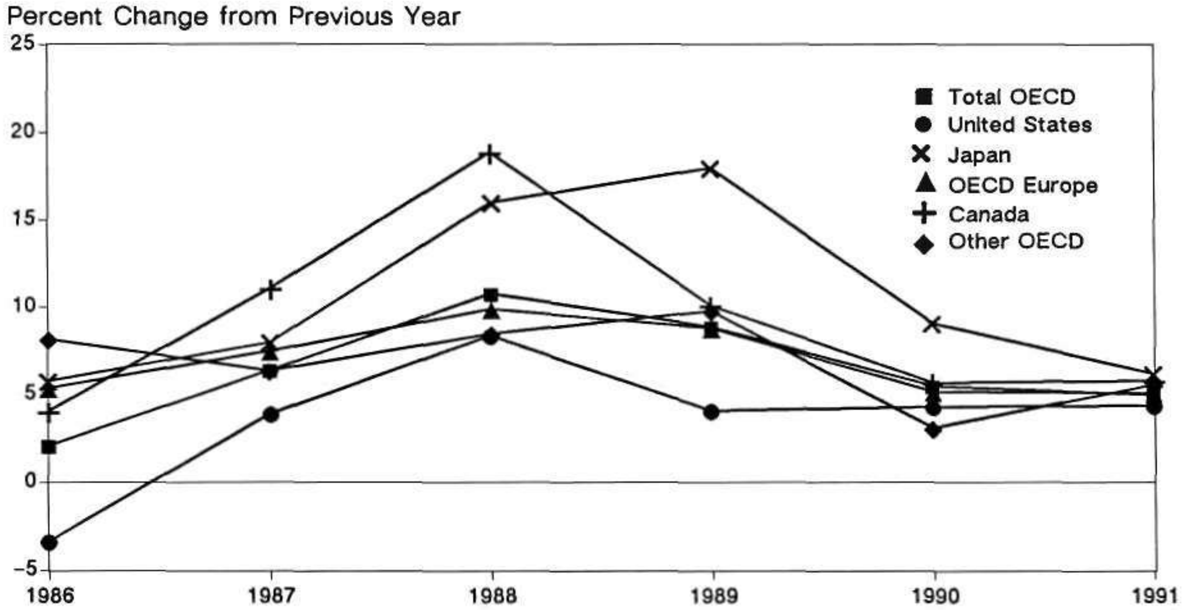
- Individual market segment growth is a function of the economic sector in which the major purchases occur.
- Small changes in sector spending can have a large impact on equipment demand.
- Regional annual growth rates of electronic equipment demand are determined by the weighted average of the annual growth rates of consumer and capital spending within each region.
- Each region's share of electronic equipment demand is approximately equal to its share of worldwide capital spending.

Over the past five years, the share of electronic equipment demand has shifted from the United States and Europe to Japan and the Asia/ROW nations. The fundamental reasons for this shift in regional demand are as follows:

- Japan and the Asian NICs were the major suppliers to the US import shopping spree from the 1983 through 1985 period. As a result, at different times throughout the period, they all experienced heavy capital spending growth to expand production capacity, productivity, and competitiveness. This resulted in increased demand for electronic equipment (data processing, industrial automation, and communications). Figure 4-7 shows that Japanese capital spending remained strong through the 1985 downturn in the United States, as did that of the Asia/ROW region.

Figure 4-7

Worldwide and Regional Capital Spending—1986-1991



Source: Dataquest (August 1990)

- Since 1987, as the benefits of this Japanese and Asian expansion have been realized in terms of increased disposable incomes, consumer spending in these countries has surged (see Figure 4-7).

Electronic Equipment Demand Forecast—1990 and 1991

Forecasts by economists at The Dun & Bradstreet Corporation suggest a considerable slowing of worldwide capital spending through 1991. As shown in Figure 4-8, capital spending is forecast to slow from nearly 9 percent in 1989 to approximately 5 percent in 1991.

The impact that this slowdown is expected to have is that growth in demand for electronic equipment will also drop slightly, from 5.7 percent in 1989 to 5.6 percent in 1990, followed by an increase in the growth rate to 7.3 percent.

The 1989 through 1991 worldwide demand forecast by application market is given in Figure 4-9. This is based on Dataquest's forecast, which is shown in comparison to the OECD worldwide capital and consumer spending forecast in Figures 4-6 and 4-7.

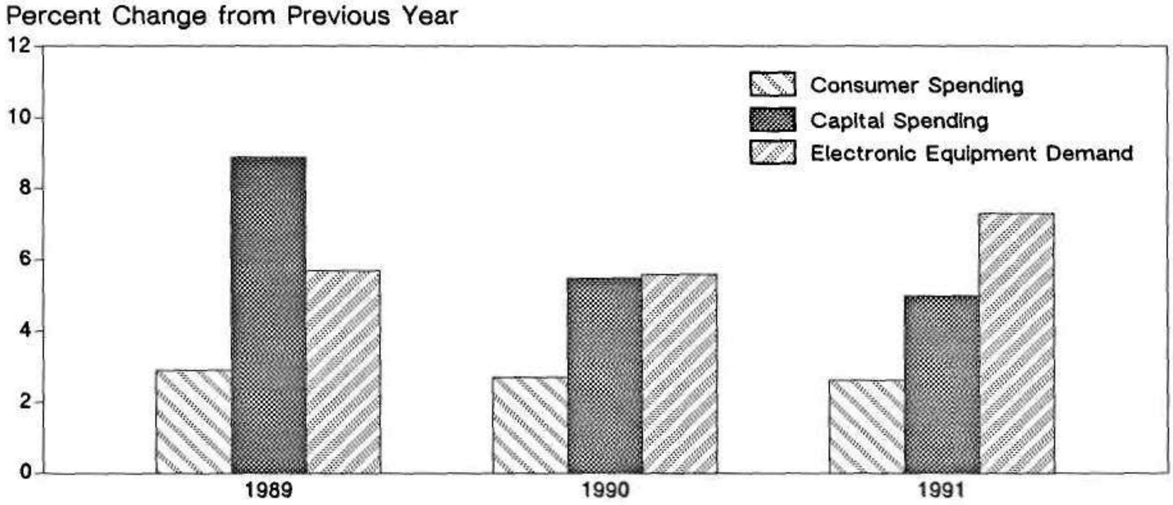
Two Strategic Issues Regarding the Demand Forecast

What Is the Regional Economic Impact on Electronic Equipment?

North America. The annual growth of the real US GNP (adjusted for inflation) is expected to increase during the second half of 1990, reaching an annualized rate of 4.0 percent by the fourth quarter. The first quarter of 1991 is expected to show slower growth in GNP at 3.8 percent. The GNP growth rate is forecast to decline throughout 1991, reaching a rate of 2.8 percent by the fourth quarter. For the year 1991, US GNP growth is expected to be 3.4 percent. The capital spending forecast follows GNP growth closely. A strong second half of 1990 is expected to lift growth rates of capital spending over those of 1989. Growth in capital spending in 1990 is expected to be at 4.0 percent, up from 3.5 percent in 1989. In 1991, despite a slight decline in growth throughout the year, capital spending is expected to grow at 7.1 percent. As a result, the growth of North American demand for electronic equipment is expected to increase modestly beginning in the second half of 1990 and continuing through 1991.

Figure 4-8

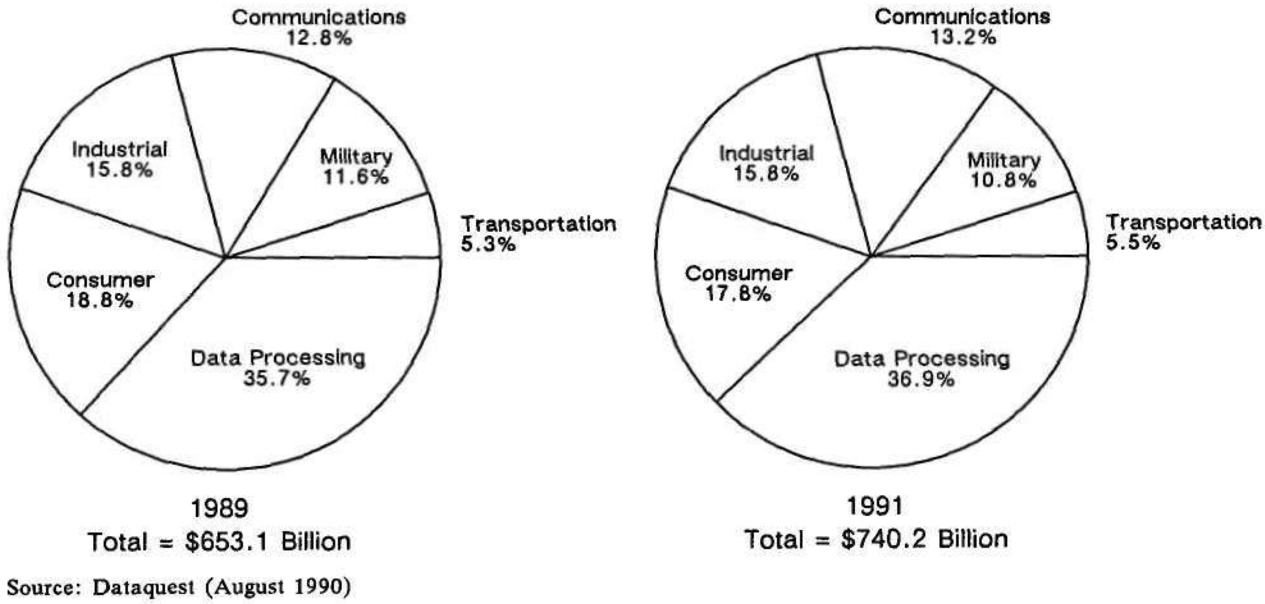
Worldwide Electronic Equipment Demand and Consumer and Capital Spending Annual Growth—1989-1991



Source: Dataquest (August 1990)

Figure 4-9

Worldwide Electronic Equipment Demand Share Estimate and Forecast by Application Market Share—1989 and 1991



Source: Dataquest (August 1990)

Europe. The European electronic equipment demand is forecast to grow at a decreasing annual rate through 1991. Again, this is a result of the forecast slowing of real GNP/GDP growth and its amplified impact on capital spending throughout Europe. The European countries will avoid feeling the full slowdown that is affecting the United States, largely because of the widespread capital spending by both European and Pacific Rim countries in preparation for the EEC market consolidation in 1992.

Japan and Asia/ROW. Because the capital and consumer spending growth of Japan and the Asian NICs is not expected to fall as sharply as that of the North American and European regions, the electronic equipment demand compound annual growth rate (CAGR) in these regions remains higher than in that of the other regions. The continued investment by Japanese electronics companies in offshore production will continue to stimulate demand growth in the Asian NICs. The demand share for electronic equipment therefore will continue to shift toward Asia and Japan.

What Are the Major Demand Drivers?

The application market forecast to show the highest growth still is data processing, followed by the communications and industrial segments. This is a result of the continued expansion and modernization in the Asian NICs and Japan. Modernization and productivity improvement in process in Europe also will contribute to the growth of these segments. The slower growth of the consumer and transportation segments reflects the forecast decline in consumer spending within the regions with the largest populations—North America and Europe.

The US fiscal restraint evident in the 1989 and 1990 federal defense spending budget has caused the slower growth forecast in the military segment.

Electronic Products—Largest Demand Drivers. Within those market segments showing the most demand growth, the specific products that are driving this growth are shown in Table 4-1. Table 4-2 shows those end products forecast to show the steepest decline.

What are the Factors Affecting the Supply Side?

Although a portion of market growth can be explained by changing preferences and spending patterns, still more of the growth is explained by supply-side factors.

Three major factors affecting the supply of electronic equipment are technology, cost of goods sold, and production costs. As technology improves and costs of raw materials and production decline, manufacturers become willing to supply a greater number of finished goods at the same selling price. In economic terms, this translates into a rightward shift in the market supply curve, which leads to a lower market price and a larger quantity of goods sold.

Table 4-1

Growing North American Application Markets—1989-1993
(Millions of Dollars)

	1989	1990	1993	CAGR 1989-1993
Optical Disk Drives	120	222	1,360	83.5%
3- to 4-Inch Rigid Disk Drives	2,990	4,209	7,195	24.5%
Workstations	5,398	7,160	13,222	25.1%
LANs	3,774	4,959	7,857	20.1%
Voice Messaging Systems	675	825	926	8.2%
Total	12,957	17,375	30,560	23.9%

Source: Dataquest (August 1990)

Table 4-2

Declining North American Application Markets—1989-1993
(Millions of Dollars)

	1989	1990	1993	CAGR 1989-1993
5.25-Inch Flexible Disk Drives	3,192	3,146	2,608	(4.9%)
Alphanumeric Display Terminals	1,668	1,220	442	(283.0%)
Modems	1,237	1,139	795	(10.5%)
Line Printers	1,614	1,561	1,354	(4.3%)
Electronic Typewriters	935	849	575	(11.4%)
Total	8,646	7,915	5,774	(9.6%)

Source: Dataquest (August 1990)

Electronic Equipment Production

Electronic equipment production directly determines the demand for semiconductors. The success and growth of electronic equipment producers within a given region determines the size and growth of the total available market for semiconductors within that region.

The success and growth of electronic equipment producers depends to a large degree on their products. However, the economic conditions of the region—labor costs, interest and currency exchange rates, and the availability of patient investment capital—play a large role as well. These factors determine productivity and hence competitiveness, thus influencing a company's ability to compete for worldwide demand for its products.

This chapter takes the next step down the demand waterfall shown in Figure 4-10 and relates the worldwide and regional demand for electronic equipment discussed above to the production of electronic equipment and hence to the demand for semiconductors.

Background

Electronic equipment producers build end products by assembling printed circuit boards containing semiconductors, other electromechanical or mechanical devices, and a power supply into a package or container. The manufacturing steps are as follows:

- Fabrication of the individual subassemblies, PC boards, and packaging
- Assembly of all these pieces
- Test and verification that the product works and meets specifications

These manufacturing steps frequently involve the need for labor with good manual skills. Low-cost production translates to low-cost but highly skilled labor and considerable automation of much of the fabrication and testing portions of the process.

During the 1970s, emerging semiconductor technology enabled more and more functionality in smaller and smaller physical packages, and electronic products generally became more of a commodity. Successful producers required very large production volumes to be truly competitive.

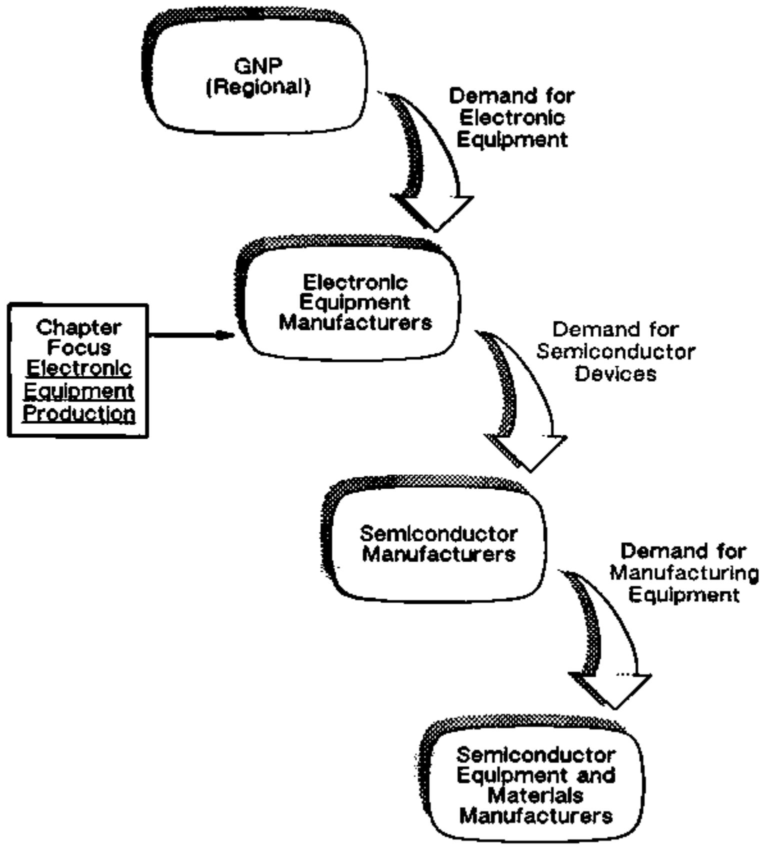
Meanwhile, early in the 1970s, Japan began to execute a multiphased strategy to accomplish a national objective: to become a world-class producer of consumer, communications, and data processing equipment. The execution of this was truly national in scope and involved teamwork between the government, sources of patient capital, and many individual business entities.

The strategy itself embodied the following four steps:

- License the technology or manufacturing rights to a key product
- Leverage Japan's manufacturing and quality assurance ingenuity and highly favorable economic climate, especially the low-cost, dedicated, and skilled labor force, to manufacture the product very cheaply in high volume

Figure 4-10

Waterfall of Demand



Source: Dataquest (August 1990)

- Capture market share in the United States and Europe (and thus generate demand appropriate to the low-cost production volume) through aggressive pricing
- Gain dominance and ownership of the product by adding market-driven proprietary enhancements as experience is accumulated

In response, during the 1970s, US electronics manufacturers began to move their production offshore to Taiwan and other Asian countries whose low-cost, highly skilled labor force and favorable economies ensured competitiveness with Japan.

In many of these countries, companies have evolved that have honed these manufacturing skills to a fine edge because of the huge production volumes they have run through their factories for US companies. These companies have either learned or licensed the requisite product technologies to develop their own products and by now, have leveraged their high-volume production capabilities into formidable competition for their original US customers.

Japan became the premier producer of consumer electronics in the early 1980s to the extent that the United States is all but out of that business now. RCA is an example of an early electronics innovator that no longer is a participant. South Korea became the offshore production site for Japan when Japanese costs rose; now South Korea is the premier producer of consumer electronics. From 1983 through 1985, Taiwan became the offshore production site for numerous US PC clones and add-in boards; now Taiwan is a serious worldwide competitor in all aspects of the PC market. Similar examples exist for computer peripherals, such as disks, printers, terminals, and modems.

Where Is Electronic Equipment Produced Today?

North America is still the dominant producer of data processing, communications, and industrial electronic products, but the trend clearly indicates significant erosion of North American suppliers. When any electronic product, such as computers, communications devices, or industrial products, reach the commodity volume level, the US economy and business climate are not in a good position to compete on an international scale with Japan and the Asian NICs. Therefore, more and more electronic equipment production—particularly high-volume production—will be done in Japan and the Asian NIC regions.

Although this trend has been going on since the 1970s, it accelerated between 1985 and 1986 when the US worldwide production share fell from its 1984 level of 48 percent to 44 percent in 1986. The dramatic shift in power from US suppliers to Japanese and Pacific Rim suppliers began with the 1984 boom market in the United States; it is continuing today. The following three major events occurred during the 1984 through 1989 period:

- The 1985 near-recession
- The application of commodity supply rules by Japanese and Asian suppliers
- US suppliers weakened and reduced

In order to understand where the production is today and appreciate where it will be tomorrow, a review of the 1984 through the 1988 events follows.

1984—A Year of Excessive Demand

All sectors of the US economy were engaged in vigorous buying in 1984; it was a very good year. Capital spending was up 17.7 percent over 1983. Consumer spending was up 4.4 percent, and government spending was up more than 4.5 percent. Demand for all types of products was very high; electronic equipment was no exception. Among electronic products, demand was especially strong for personal computers, work group and small departmental computers, manufacturing systems, and communications systems. Consumer products such as TVs, VCRs, and home appliances were also in high demand.

Also by 1983 and 1984, a crowd of new North American companies emerged, manufacturing communications equipment, personal computers, PC peripherals, and related products. Many producers of such equipment from Japan, Taiwan, and South Korea also were entering the US market during this period.

During 1984, the beneficiaries of the buying spree were both domestic equipment producers and foreign importers. The extremely high dollar plus the indigenous superior productivity of Japanese and Asia/ROW economies made their products very competitive in the United States.

US Equipment Producers Flourish

In spite of their inferior competitiveness, US equipment suppliers still did well because of the very high demand and the "newness" of many of the data processing and communications products. This was especially true of the PC product segment that was experiencing extraordinary demand. Many domestic producers were successfully gaining share of this "hypermarket." US producers of PCs, small microprocessor-based systems, peripherals, and a variety of communications products experienced growth in 1984 ranging from 70 percent for PCs to 20 percent for communications equipment.

Market research forecasts during 1984 were extremely bullish for PCs and communications products. Many US companies geared up for expanded production, and because DRAMs and some microprocessors were in short supply, ordered aggressively.

The Bubble Bursts

The situation was ripe for a fall. This plunge started in early 1985 when US capital spending growth fell off to only 6.7 percent in 1985 (and plummeted to a negative 4.5 percent growth in 1986). A sharp decline in demand for electronic equipment during 1985 and 1986 resulted.

US Loses Numerous Equipment Producers

When US demand fell off, US equipment producers were unable to compensate for the reduced domestic demand by increasing their exports. They found themselves fundamentally unable to compete with Japanese and Asia/Pacific producers. The sharp reduction in US equipment demand also put severe competitive pressure from Japanese and Asian producers on US equipment producers in the US market. (See Chapter 2 for a review of how Japanese and Asia/Pacific suppliers excelled by applying the basic rules of marketing commodity products.)

Many US suppliers, unable to meet competitive pressure in a declining market, went out of business, were acquired by larger suppliers, or were acquired by Japanese, Asian, or European companies. The net result was that by the end of 1986, there were significantly fewer US electronic equipment producers, and the foreign producers were all that much stronger.

Thus, because of their fundamental superior competitiveness, the Japanese and Asia/ROW producers were less affected by the US equipment demand decline. Not only were they effectively able to balance the reduced US demand with sales to other markets, but they also increased their share of the declining US market.

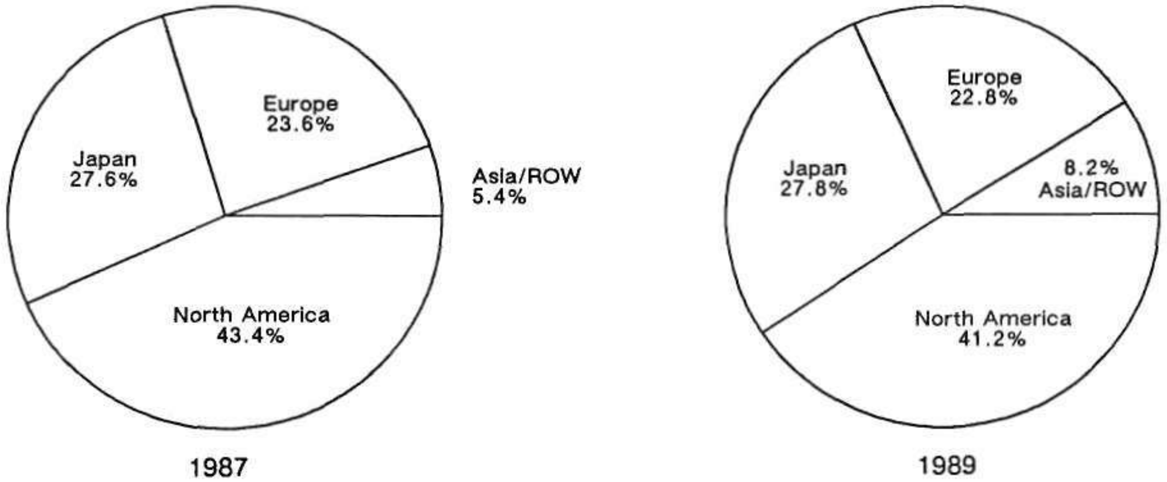
By mid-1987, the US dollar, interest rates, and prices had fallen to the extent that the United States was extremely competitive. At that time, the United States commenced an export effort that has stimulated the US economy in concert with all other regional economies. Worldwide capital spending and equipment demand surged. The result was the extraordinary recovery of electronic equipment production from 1985's low point through mid-1989. Since that time, equipment production growth has slowed as the growth of worldwide capital spending slowed.

During this dynamic recovery period leading up to 1989, the replacement by foreign suppliers of the equipment producers shaken out by the 1985 recession and the offshore move by many US producers contributed to a continuing but more gradual shift in electronic equipment production to Japan and the Asia/ROW countries.

Figure 4-11 illustrates this production shift from North America to Japan and the Asian NICs. The North American share of electronic equipment production declined from 43.4 percent in 1987 to 41.2 percent in 1989, while Japanese and Asia/ROW share climbed to 36.0 percent in 1989. Taken separately, the production share for the Asia/ROW region increased from 5.4 percent in 1987 to 8.2 percent in 1989. European share of worldwide electronic production dropped from 23.6 percent in 1984 to 22.8 percent in 1989.

Figure 4-11

Regional Shares of Worldwide Electronics Production—1987 and 1989



Source: Dataquest (August 1990)

Electronic Equipment Production Forecast—1990 and 1991

The 1990 and 1991 Dataquest forecast for electronic equipment production is presented in Figures 4-12 through 4-17.

Three Strategic Issues Regarding Equipment Production

What Regional Production Shifts Will Occur During the Forecast Period?

North America. Dataquest forecasts that North American production will increase 5.8 percent in 1990 to $285 billion, down slightly from the 6.0 percent growth of 1989. The negative impact of the capital spending forecast is not expected to be as dramatic for production as for demand because of continued exports to Europe of computer, industrial, and communications products.

Dataquest predicts reasonable growth for the 1989 to 1991 period in each of the six application market segments, except military and consumer, with CAGRs in excess of 6.5 percent in each of the four remaining segments (see Table 4-3). PCs and workstations will drive the data processing segment growth: local area networks (LANs) are expected to drive the communications segment. The US LAN market alone is forecast to grow approximately 33 percent to about $5.5 billion in 1990.

Europe. The 1992 effect is the preparation by European, Japanese, South Korean, and some US companies for the single European market of 1992. Real GNP growth in the EEC is expected to fall from 3.6 percent in 1989 to 2.9 percent in 1990 and finally 2.8 percent in 1991. Data processing, communications, and consumer product manufacturing will strengthen as companies, both foreign and domestic, build production facilities within the EEC. Only the data processing and transportation market segments will maintain double-digit growth rates throughout the period.

Japan. The Japanese economy continues to achieve strong growth rates. These rates are, however, expected to decline slightly over the next two years. After a real GNP growth rate of 4.8 percent in 1989, the growth rates are expected to decline to 4.5 percent and 4.3 percent in 1990 and 1991, respectively. Recently, we have seen a devaluation of the yen. The likely effect of this relatively weaker yen is higher exports and lower imports. Japanese electronic equipment production is not forecast to grow as rapidly as strong domestic demand. As Japan continues to contract equipment production to other Asian countries, it is expected that its share of worldwide production will fall slightly.

Asia/ROW. Asia/ROW electronic production should be the fastest-growing of all four major regions through the forecast period, partly because Japan and the United States have been shifting production to this region. This growth also is driven by consumer products, PC clones, and related products. Asia/ROW consumer production is forecast to increase 13.9 percent in 1990; data processing should increase 14.2 percent. The Asia/ROW telecommunications segment is growing rapidly, but to date it is still a relatively small share of total production.

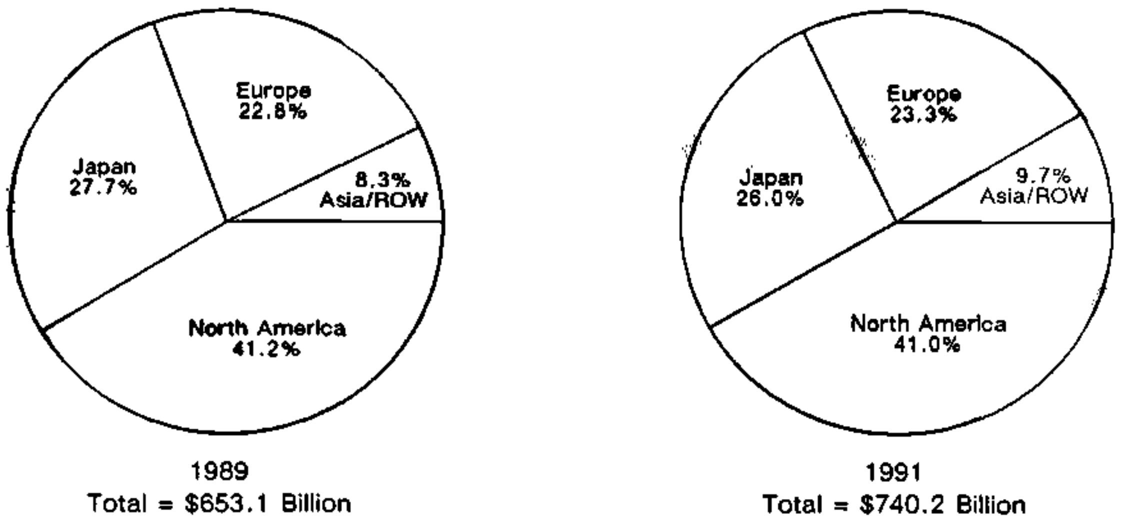
The consumer product segment is expected to undergo such dramatic growth because of the huge potential demand from regions just beginning to open their markets to consumer product imports. Vast markets such as China and Thailand represent massive potential to Asia/ROW producers as well as to Japan-based companies that have built production facilities in this region.

What Will Each Region Spend on Semiconductors?

Table 4-4 shows the semiconductor demand and forecast by region. The worldwide projections for semiconductor demand (expenditures), also shown in Table 4-4, are expected to grow throughout 1990, although 1990 is forecast to be a year of negative growth compared with 1989. Overall 1990 semiconductor demand is expected to decline by 1 percent in 1990, followed by a growth rate of 17 percent in 1991. The merchant market is expected to reach $60.9 billion in 1990 and to grow to $65.6 billion in 1991.

Figure 4-12

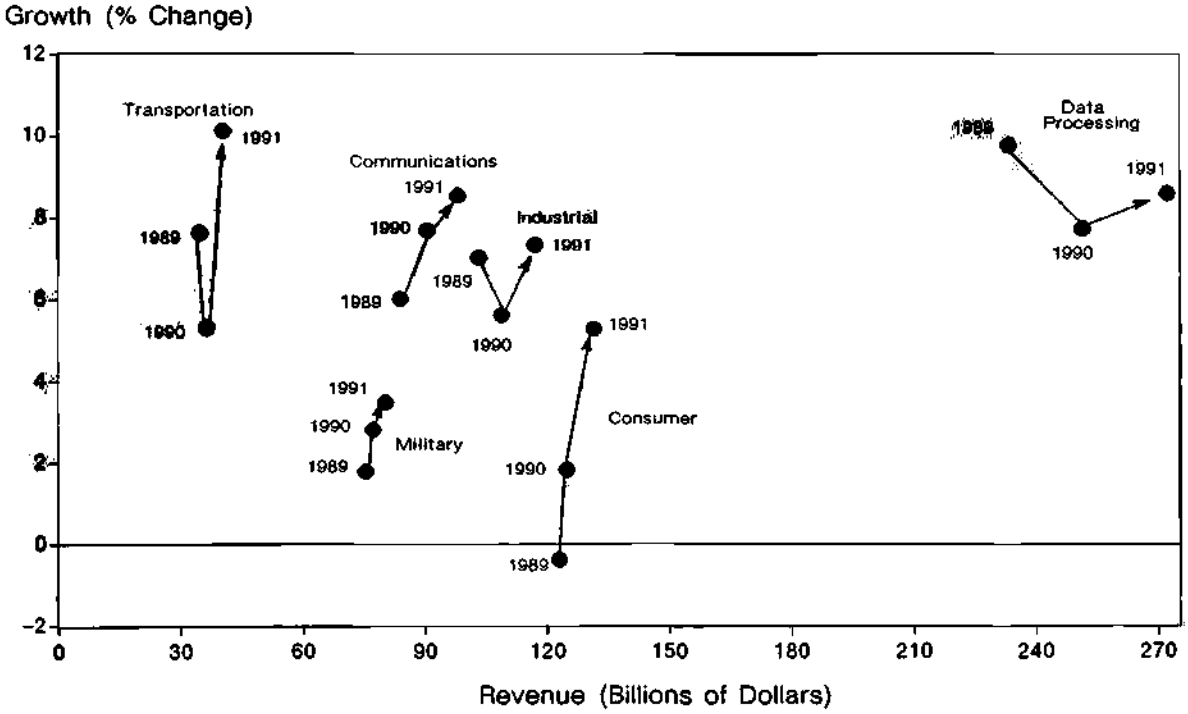
Regional Shares of Worldwide Electronic Equipment Production—1989-1991



Source: Dataquest (August 1990)

Figure 4-13

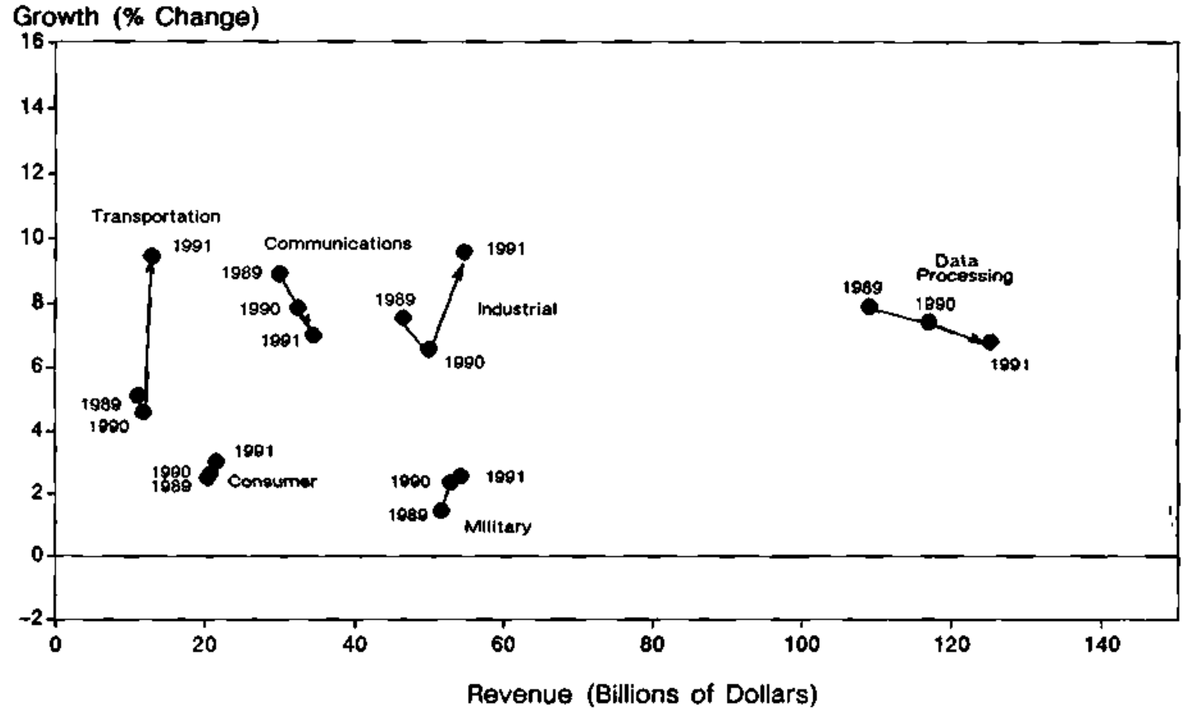
Growth Trends for Application Segments—Worldwide



Source: Dataquest (August 1990)

Figure 4-14

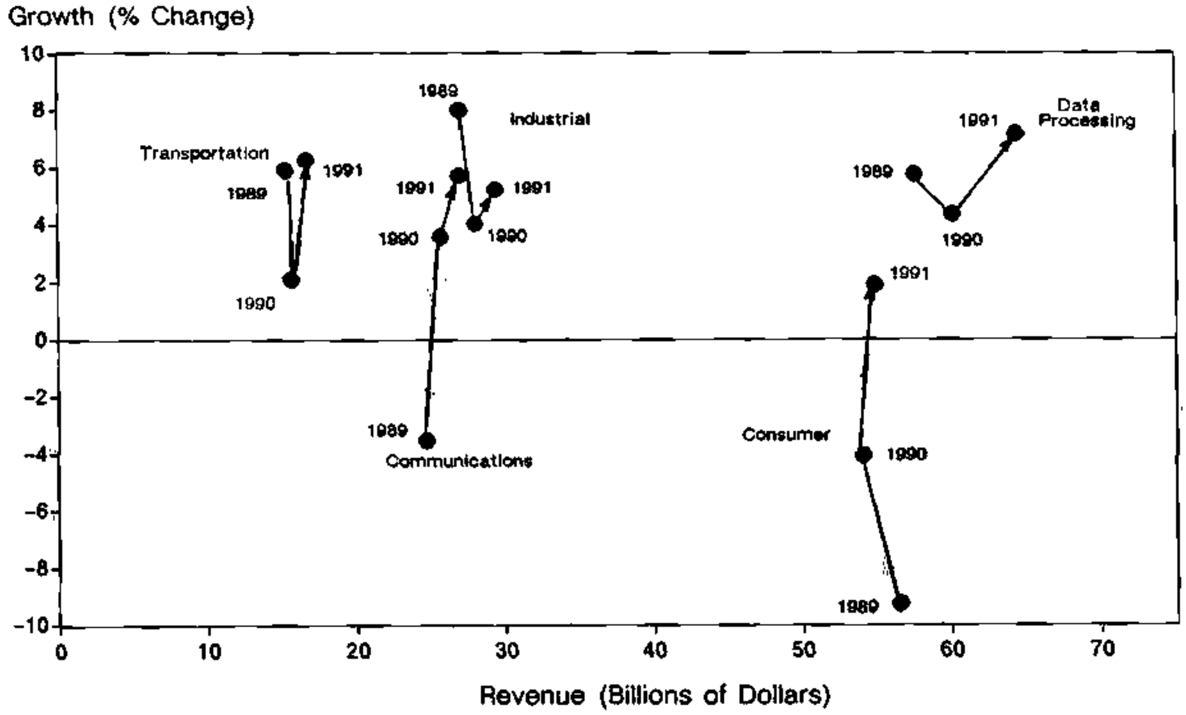
Growth Trends for Application Segments—North America



Source: Dataquest (August 1990)

Figure 4-15

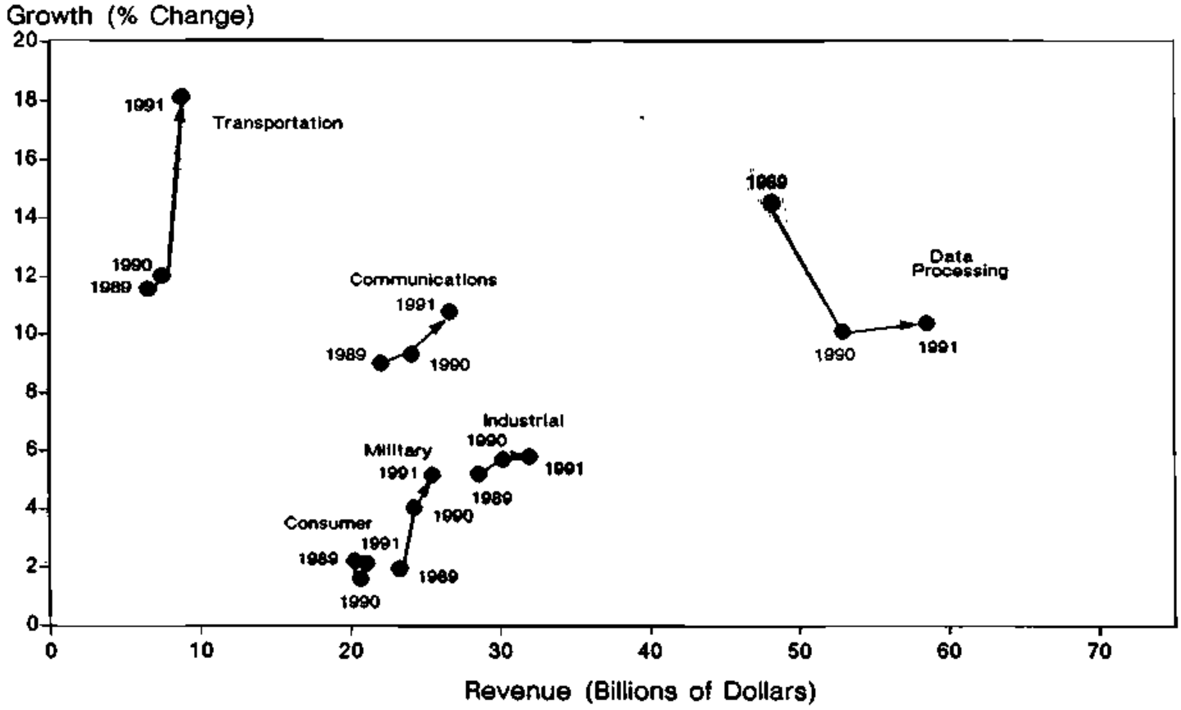
Growth Trends for Application Segments—Japan



Source: Dataquest (August 1990)

Figure 4-16

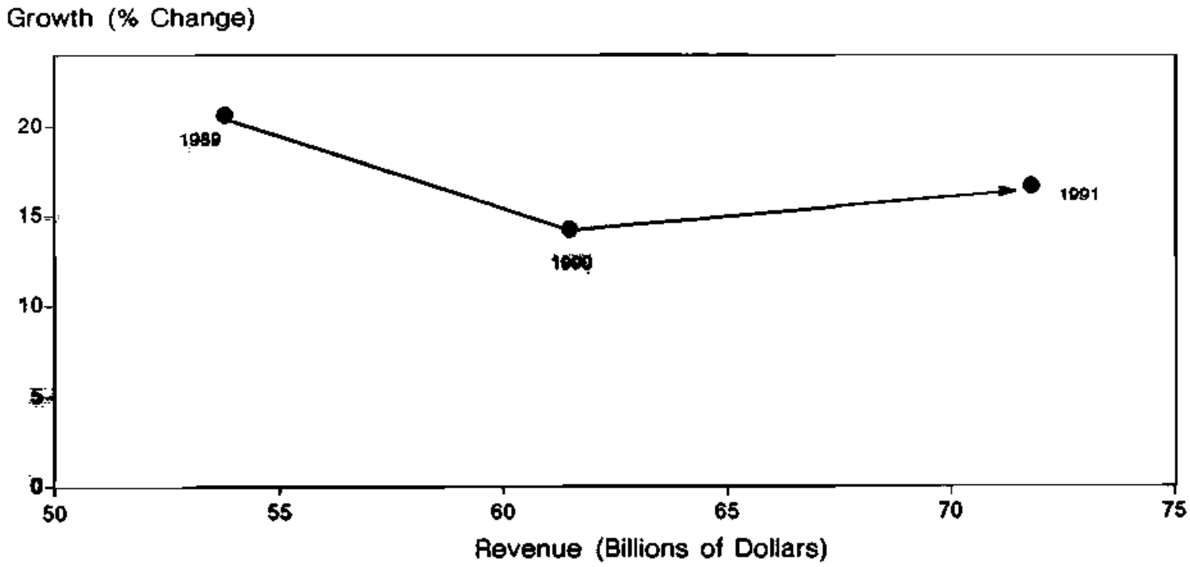
Growth Trends for Application Segments—Europe



Source: Dataquest (August 1990)

Figure 4-17

Electronic Equipment Growth Trends—Asia/ROW



Source: Dataquest (August 1990)

Table 4-3

North American Electronic Equipment Production
History and Forecast—1989-1991
(Millions of Dollars)

Segment	1989	1990	1991	CAGR 1989-1991
Data Processing				
Computers	74,757	80,892	88,073	8.5%
Data Storage Subsystems	17,998	19,736	20,254	6.1%
Data Terminals	2,584	2,081	1,712	(18.6%)
Input/Output	11,336	12,281	13,287	8.2%
Dedicated Systems	5,324	5,333	5,481	1.5%
Subtotal	108,941	116,997	125,098	7.2%
Communications				
Premises Telecom Equipment	12,517	13,866	15,102	9.8%
Public Telecommunications	7,175	7,590	8,019	5.7%
Mobile Communications	6,418	6,748	7,083	5.1%
Broadcast and Studio	2,145	2,315	2,465	7.2%
Other	1,660	1,720	1,790	3.8%
Subtotal	29,915	32,239	34,459	7.3%
Industrial				
Security/Energy Management	2,506	2,639	2,822	6.1%
Manufacturing Systems	16,286	16,965	18,538	6.7%
Instrumentation	8,122	8,436	9,142	6.1%
Medical Equipment	6,117	6,485	6,896	6.2%
Civil Aerospace	8,149	9,411	10,807	15.2%
Other	5,719	6,053	6,537	6.9%
Subtotal	46,899	49,989	54,742	8.0%
Consumer				
Audio	285	292	299	2.4%
Video	5,749	5,864	6,014	2.3%
Personal Electronics	239	240	241	0.4%
Appliances	13,147	13,512	13,918	2.9%
Other	1,037	1,078	1,126	4.2%
Subtotal	20,457	20,986	21,598	2.8%
Military	51,727	52,918	54,263	2.4%
Transportation	11,292	11,828	12,897	6.9%
Total	269,231	284,957	303,968	6.3%

Source: Dataquest (August 1990)

Table 4-4

Worldwide Semiconductor Consumption and Consumption Share by Region—1989-1991 (Billions of Dollars and Percent Share)

	Demand ($B)			Demand Share (%)		
Region	1989	1990	1991	1989	1990	1991
North America	17.9	17.2	19.9	31.4%	30.8%	30.3%
Europe	9.8	9.7	11.4	16.9	17.4	17.4
Japan	23.0	22.4	26.1	40.7	40.0	39.8
Asia/ROW	6.5	6.6	8.2	11.0	11.8	12.5
Total	57.2	56.0	65.6	100.0%	100.0%	100.0%

Source: Dataquest (August 1990)

CHAPTER 5

Semiconductor Demand

In 1989, more than $57 billion worth of semiconductor products were consumed worldwide. This demand constituted 12 percent annual growth.

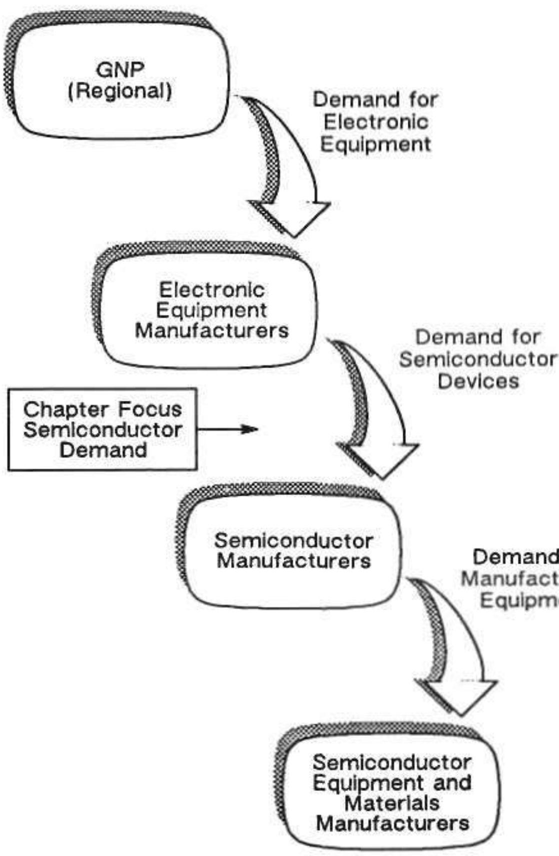
The growth in 1989 followed three years of sustained growth after the 1985 recession, in which merchant demand was only $24 billion. After doubling in the three years between 1985 and 1988 and realizing a 33 percent rate of growth in 1988, the market slowed to only a 12 percent growth rate in 1989.

Although semiconductor demand and production represent the next step down the waterfall of demand (see Figure 5-1), this chapter focuses only on semiconductor demand; Chapter 6 focuses on semiconductor production. This chapter describes the underlying forces that drove semiconductor demand and sustained the extraordinary growth from 1986 to 1989; it also provides the forecast for 1990 and 1991. The chapter contains the following three sections:

- Background—The underlying forces of demand are addressed as follows:
  - Reasons for sustained growth—What has caused the sustained growth in demand over the last three years?
  - Semiconductor producers—Who is satisfying the demand?
  - Demand sources—Where is the demand being generated?
    - Equipment market segments
    - Semiconductor products
    - Geographical regions
- Demand forecast—1990 through 1991 worldwide and regional demand forecast by product type and electronic end-application market, including the economic and end-product demand drivers
- Strategic issues—Key issues relating to the semiconductor demand

Figure 5-1

Waterfall of Demand



Source: Dataquest (August 1990)

Background

Reasons for Sustained Growth—1985 through 1989

Primarily, semiconductor demand growth is a function of equipment production growth. It is assumed that on a worldwide basis, equipment production equals equipment demand, and equipment demand growth is driven by capital spending growth. Figure 5-2 shows the historical correlation between the annual growth of worldwide capital spending, electronic equipment production, and semiconductor consumption for the period from 1970 through 1989. Examination of Figure 5-2 suggests that one contributor to the sustained growth of electronic equipment production was the growth in worldwide capital spending during 1987 and 1988.

The resulting if-sold values of worldwide electronic equipment production and the corresponding semiconductor consumption from 1986 through 1989 are shown in Table 5-1 along with their respective CAGRs. As the table shows, electronic equipment production has increased more than 40.0 percent from its 1986 level, to more than $653 billion in 1989, a 1986 through 1989 CAGR of approximately 12.0 percent. Semiconductor consumption, including captive consumption (defined herein), has doubled its 1986 recession level for a CAGR of 21.5 percent to more than $54 billion in the same period.

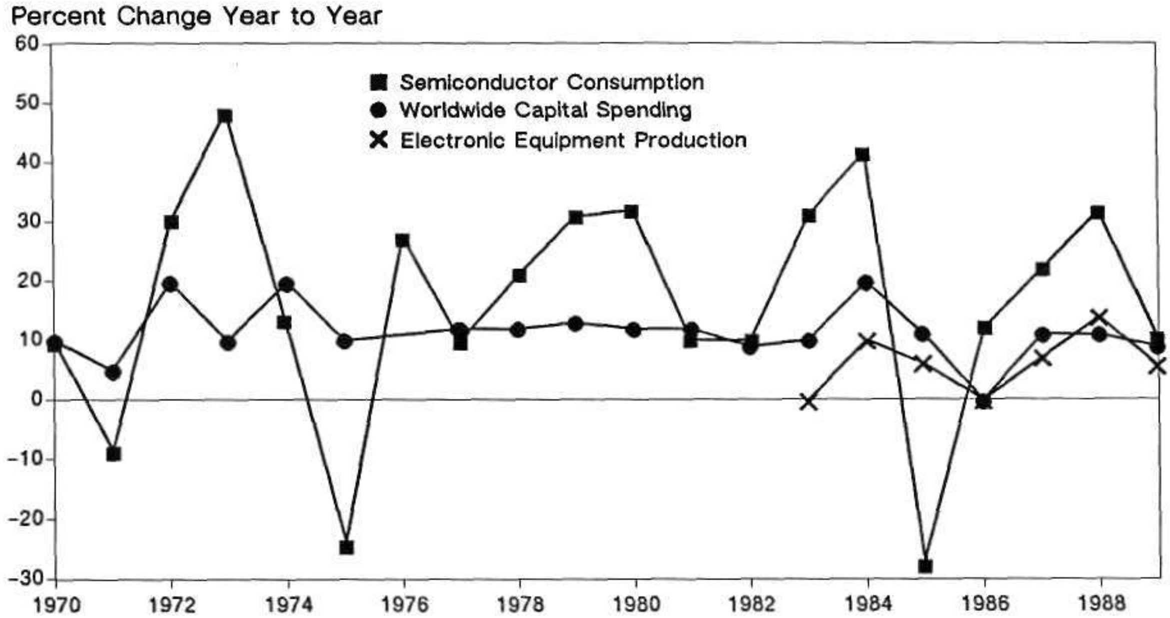
Secondarily, the sustained growth in semiconductor demand is from increased semiconductor pervasiveness—particularly in those equipment market (application) segments that represent the highest electronic equipment volume and most rapid growth. Table 5-1 shows that the semiconductor demand value was 7.3 percent of the electronic equipment value in 1986, which increased to more than 8.5 percent by 1988.

Semiconductor Producers

Because semiconductor manufacturers supply their products to electronic equipment producers, within any region, the level of demand for semiconductor products is created by the level of electronic equipment production. More than 200 companies throughout the world supply their products to electronic equipment producers. These companies

Figure 5-2

Worldwide Capital Spending, Electronic Equipment Production, and Semiconductor Demand Growth Rates—1970-1989



Source: Dataquest (August 1990)

Table 5-1

Worldwide Electronic Equipment and Semiconductor Demand—1986-1989

	1986	1987	1988	1989	CAGR 1986-1989
Electronic Equipment Production	$460.4	$525.3	$618.1	$653.1	12.4%
Semiconductor Demand	$ 33.7	$ 41.5	$ 54.5	$60.5	21.5%
Pervasiveness	7.3%	7.9%	8.8%	9.3%	

Note: Includes captive suppliers
Source: Dataquest (August 1990)

can be characterized into one of the following three broad classifications:

- Independent manufacturer
- Division (of a larger corporation) manufacturer
- Captive manufacturer

The first two of these classifications, both of which are merchant suppliers, compete in the worldwide merchant market to supply semiconductor products to manufacturers of electronic equipment worldwide. The third classification—captive—supplies products only for internal consumption to satisfy its own electronic equipment production requirements. These three types of manufacturing companies will be discussed in more detail in Chapter 6. It is important to note that the distinction between merchant and captive suppliers is more prevalent in the United States than in Japan, where most semiconductor production is integrated into a larger electronics company.

Semiconductor Demand Sources

Semiconductor demand can be viewed in the following three ways:

- Demand generated by the individual equipment market application segments
- Demand generated for semiconductor product types
- Demand generated within a geographic region

Equipment Market Segments

Because electronic equipment production creates semiconductor demand, the volume and growth of semiconductor demand by electronic equipment application markets is fundamental to understanding sources of demand growth. The application market segments of electronic equipment production, as defined in Chapter 4, are as follows:

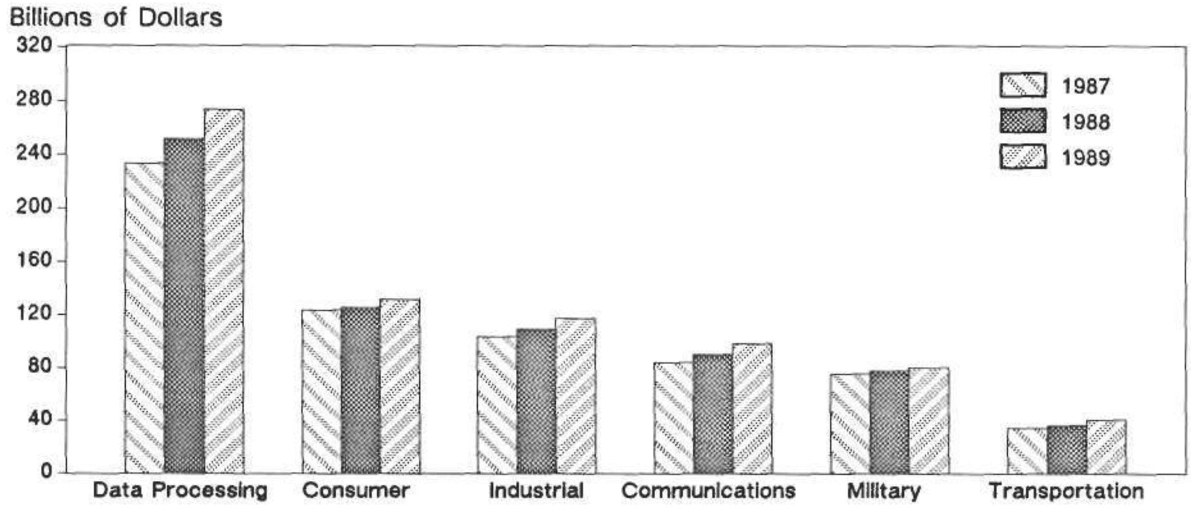
- Data processing
- Communications
- Industrial
- Consumer
- Military
- Transportation

Within the electronic equipment market, the highest growth markets were identified in Chapter 4 to be the data processing, communications, and consumer segments. Figure 5-3 depicts the worldwide electronic equipment market, and Figure 5-4 depicts the resulting semiconductor consumption by electronic equipment market segments for 1987 through 1989. Not surprisingly, the segments with the highest demand and demand growth were the data processing, consumer, and communications segments, and these were also the highest-volume and highest-growth segments of semiconductor demand.

In Figure 5-4, it can be seen that more than two-thirds of the 1989 worldwide semiconductor consumption ($56 billion) has been by producers of data processing, consumer, or communications products. Consumption of semiconductors by these producers has experienced a CAGR of more than 26 percent from 1987 through 1989.

Figure 5-3

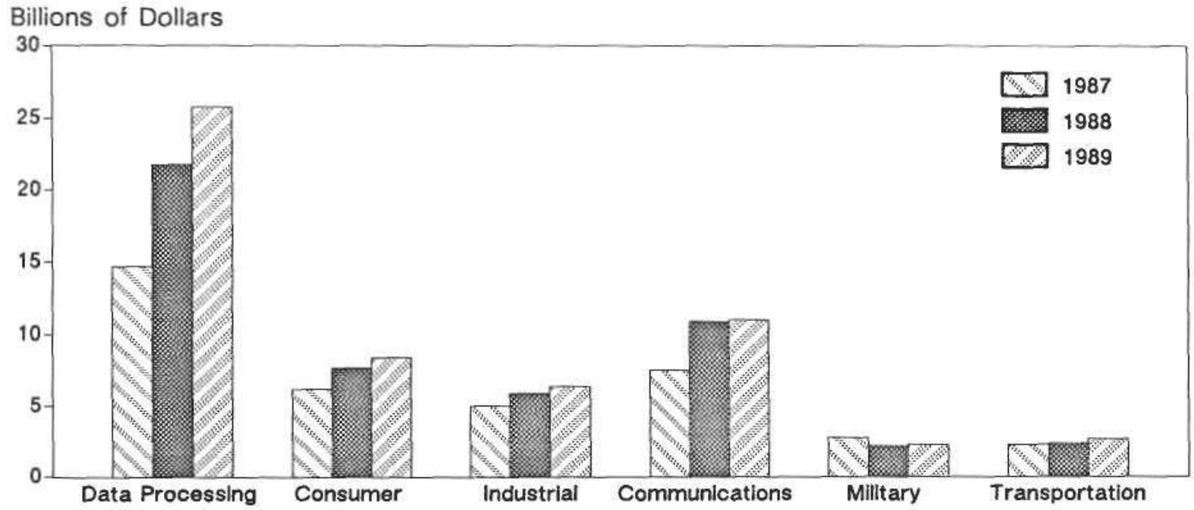
Worldwide Electronic Equipment Market Growth
by Application Market Segment—1987-1989



Source: Dataquest (August 1990)

Figure 5-4

Worldwide Semiconductor Demand by Market Segment—1987-1989



Source: Dataquest (August 1990)

Semiconductor Products

In response to semiconductor demand, the semiconductor industry supplies billions of semiconductor devices to electronic equipment producers worldwide. These devices consist of many different types of products, including diodes, transistors, ICs, and optoelectronic devices. Dataquest classifies these products into the following major categories:

- Discrete and optoelectronic devices
- Integrated circuits

Discrete Devices. The term "discrete" refers to a packaged semiconductor device that has a single function, meaning that one or several functioning circuits are in the package. Dataquest divides the discrete market into seven separate categories: small signal and power transistors; small signal, power, and zener diodes; thyristors; and other discretes. Optoelectronic devices include light-emitting diodes (LEDs), photodiodes, solar cells, lasers, optocouplers, and phototransistors.

ICs. An integrated circuit is a single chip that contains more than one active device. For example, it may have a number of transistors, diodes, resistors, or capacitors as part of an electronic circuit. Integrated circuits vary widely by function. They can perform digital or linear electronic functions and may be based on a number of basic technologies, such as bipolar or MOS.

Dataquest further classifies ICs into memory, microcomponents, logic, and analog. These categories are described in the following paragraphs with some examples of commercially available product types.

Memory ICs. Memory ICs are designed for the storage and retrieval of binary information. Read/write memory, generally referred to as random-access memory (RAM), allows storage and retrieval of information created by the user. When such information is retained only as long as power is supplied to the device, the memory device is referred to as "volatile." Examples of volatile memory products are as follows:

- Dynamic RAM (DRAM)
- Static RAM (SRAM)
- Hierarchical RAM (HRAM)

Examples of nonvolatile memory products, which do not lose information when power is removed, are the following:

- Read-only memory (ROM)
- Programmable read-only memory (PROM)
- Erasable PROM (EPROM)
- Electrically erasable PROM (EEPROM)

Microcomponents. Microcomponents are further categorized into microprocessors, microcontrollers, and microperipherals, as follows:

- Microprocessor (MPU)—A microprocessor can be a single chip or a collection of chips that function together as the central processing unit (CPU) of a system.
- Microcontroller (MCU)—A microcontroller is an IC containing a CPU, memory, and input/output (I/O) capability; it can perform all the basic functions of a computer without the additional ICs.
- Microperipheral (MPR)—Microperipherals are support devices for microprocessors or microcontrollers. They either interface external equipment or provide system support. Examples are as follows:
  - Disk-drive controllers
  - PC logic chip sets
  - Graphics controllers
  - Bus controllers
  - Serial and parallel I/O controllers

Logic Devices. Logic may be visualized as the "glue" that surrounds the IC devices discussed previously. They handle digital signals in a variety of ways: routing, multiplexing, demultiplexing, encoding/decoding, counting, and comparing. Logic devices also are used to implement I/O interfaces. They are divided into two categories—standard and ASIC—shown as follows:

- Standard logic—Standard logic ICs are readily available off the shelf from a number of suppliers. They come in predefined logical functions in a variety of arrangements. Examples of standard logic types are as follows:
  - Bipolar
    - Transistor-transistor logic (TTL)
    - Emitter-coupled logic (ECL)
  - Metal-oxide semiconductor (MOS)
- ASICs—ASICs are integrated circuits designed or adapted by the user for a specific application or set of logical functions. Examples of ASIC types are as follows:
  - Programmable logic devices (PLDs)
  - Gate arrays

— Cell-based design

— Full-custom design

Semiconductor Demand by Product—1988 through 1989

The worldwide semiconductor demand and demand growth by product category are shown in Table 5-2. The major category with the highest growth from 1988 to 1989 is that of optoelectronic devices, with a growth rate of 20.6 percent. The table also shows that the market for discrete products declined 0.7 percent between 1988 and 1989. ICs, which represent more than 80 percent of total product consumption, posted a growth rate of 14.3 percent during the same period. Table 5-2 includes consumption of products manufactured by merchant market suppliers. If a manufacturer supplies the merchant market and captive producers, the consumption of its entire production is included. Manufacturers that exclusively supply captive producers are not included in these consumption figures.

Within the IC category, both the largest-volume and the highest-growth area was MOS digital products, with a growth rate of 22.4 percent. MOS digital products represent more than one-half (57.7 percent) of total semiconductor consumption. Within this category, MOS memories showed a growth rate of 39.9 percent, whereas MOS microcomponents and logic experienced a growth rate of 14.8 percent and 3.8 percent, respectively. MOS memories represent nearly 29.0 percent of total semiconductor consumption, whereas microcomponents and logic devices together represent almost 30.0 percent.

Table 5-3 lists the top ten semiconductor products in terms of annual growth in 1989 over 1988. These ten products had an aggregate annual growth of 28.0 percent in 1989 over 1988. The remaining products grew only 3.3 percent over 1988.

The electronic equipment products driving the demand for these highest-growth semiconductor products are PCs, small-scale computers, technical workstations, graphics workstations, personal peripherals such as disks and small laser printers, and LANs that tie all of these desktop systems together.

Table 5-2

Worldwide Semiconductor Consumption—1988-1989 (Millions of Dollars)

	1988	1989	Growth 1988-1989
Total Semiconductor	$50,859	$57,213	12.5%
Total IC	$41,068	$46,924	14.3%
Bipolar Digital	$ 5,200	$ 4,510	(13.3%)
Memory	689	540	(21.6%)
Logic	4,511	3,970	(12.0%)
MOS Digital	$26,988	$33,024	22.4%
Memory	11,692	16,361	39.9%
Micro	7,144	8,202	14.8%
Logic	8,152	8,461	3.8%
Analog	$ 8,880	$ 9,390	5.7%
Total Discrete	$ 7,612	$ 7,662	(0.7%)
Total Optoelectronic	$ 2,179	$ 2,627	20.6%

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1990)

Table 5-3

Top Ten Demand Growth Semiconductor Products 1989 over 1988

Product	Annual Growth
MOS ASIC—PLD	53%
MOS DRAM Memory	46%
MOS Specialty Memory	41%
MOS SRAM Memory	29%
MOS ASIC—Gate Arrays	20%
MOS ASIC—CBIC	17%
MOS Microperipherals	15%
MOS Microcontrollers	14%
Bipolar ASIC—CBIC	14%
Bipolar ASIC—Gate Array	13%
Aggregate Annual Growth	28%
All Other Products	3.3%

Note: Excludes captive demand
Source: Dataquest (August 1990)

The demand for MOS DRAM memories, fast 32-bit microprocessors, ASICs, and other MOS microcomponents grew so rapidly during late 1987 and early 1988 that a serious supply shortage existed. Although this supply shortage eased in 1989, these products still are in great demand and their growth continued in 1989. The 1990 and 1991 demand forecast for these products appears in the subsection entitled "Semiconductor Demand Forecast—1990 and 1991."

The shortage of DRAMs and SRAMs and the associated price inflation of these devices has had a substantial impact on both the magnitude of the overall semiconductor demand growth and the role that MOS digital products have in the semiconductor industry. DRAMs make up so much of the semiconductor sales volume that variations in their price can inflate or deflate the overall industry sales volume, causing distorted views of growth or decline.

MOS Memory

The "Swing Vote" in the Semiconductor Industry

DRAMs make up so much of the semiconductor sales volume that they have become the "swing vote" in determining the health of the industry. In fact, DRAM prices can have a monumental impact on the overall industry sales volume and result in skewed growth or decline numbers.

During 1984, the Japanese production capacity for MOS memory expanded voraciously as the perceived PC boom appeared to be creating a huge demand for 64K DRAMs. When the bubble burst in 1985, the Japanese producers continued their high-volume production, and the supply far exceeded the demand. The 256K part also was coming onstream at that time, and the Japanese producers were anxious to push this more profitable part. Triggered by rapid price slashing, first by Micron in the United States and then by various Japanese suppliers, the price of both 64K and 256K devices plummeted during 1985 and 1986.

Faced with severe unprofitability, the major remaining US DRAM producers, with the exception of Micron and TI, withdrew from the market. The US producers, through the SIA, succeeded in gaining US government support for their accusation that the Japanese were "dumping" 64K devices (i.e., selling them at prices well below cost).

This resulted in the US-Japan Semiconductor Trade Arrangement of 1986, which required that Japan not participate in the practice of dumping and that Japan's MITI manage the Japanese production to balance supply with demand to force the DRAM prices to stabilize so that US producers could compete. It is interesting to note that when the DRAM prices were stabilized by raising prices, the effect was to generate huge additional profits for Japanese producers to reinvest in new technology. The other major element of the agreement was that Japan would actively assist the US producers in obtaining at least a 20 percent share of its market for semiconductors.

The results of this agreement are questionable, at best. MITI reduced production of DRAMs through most of 1987, and demand recovered as US and global economies heated up; by mid-1987, demand far exceeded supply and the prices of DRAMs and SRAMs were uncharacteristically high. Early in 1990, we witnessed a number of agreements between large Japanese and American semiconductor suppliers, aimed at increasing market share for US vendors in Japan.

Perhaps the best result of this agreement was the development of long-term buyer-seller agreements and dialogue that were designed to prevent the recurrence of the 1984 disaster. The objective of this new procurement-supply process was to supply and adhere to long-term forecasts on both sides of the table, thus stabilizing both the buyers' inventory control and the vendors' production scheduling.

As the PC boom of late 1987 and 1988 moderated in early 1989 and MITI advised higher production levels, the supply of MOS memories balanced demand within the first two quarters of 1989. At that time, a considerable decline in memory prices occurred, which amplified the perceived decline in semiconductor demand through 1989 and 1990 just as the inflated pricing of DRAMs in 1987 and 1988 inflated the extraordinary growth during that period.

Semiconductor Demand by Region—1988 through 1989

The worldwide semiconductor demand by region for merchant sales only is shown in Table 5-4. This table illustrates that the combined demand from the Japanese and Asia/ROW regions was $29.5 billion in 1989, or 51.6 percent of the 1989 total demand. The North American demand was more than $17.9 billion or 31.4 percent of the total. The 1985 figures are quite different. In 1985—only four years earlier—Japan and Asia/ROW represented $11.0 billion, or only 38.0 percent of the $29.0 billion total, whereas the North American demand was $13.0 billion for a 45.0 percent share.

Although the North American region has declined somewhat since 1985 as a consumer of electronic equipment relative to Japan and the Asia/ROW countries, its share of electronic production has fallen much further, as indicated by the decline in semiconductor demand share from 45.0 percent to 31.4 percent. This sharp decline in North America's share of semiconductor consumption is discussed further in the subsection entitled "What Caused the Regional Shift in Worldwide Semiconductor Demand from 1985 through 1989?"

Semiconductor Demand Forecast—1990 and 1991

The worldwide economic outlook developed in Chapter 3 highlighted a deceleration of growth of real GNP/GDP starting in mid-1989 and continuing through 1990. Beyond 1990, a healthy recovery period is forecast. The impact of this deceleration in capital spending, electronic equipment production, and semiconductor demand growth worldwide is shown in Figure 5-5. The specific impact of capital spending on worldwide equipment production by application market was discussed in Chapter 4 and is reviewed in Figure 5-6.

After experiencing a growth rate of 5.7 percent in 1989, electronic equipment production growth is expected to be slightly slower in 1990, at 5.6 percent. In 1990, Dataquest expects a stronger growth rate of 7.3 percent. Figure 5-5 also forecasts the resulting worldwide demand for semiconductors to decline 0.7 percent in 1990 after a 10.9 percent growth rate in 1989 and to rebound to grow 17.1 percent in 1991.

Table 5-4

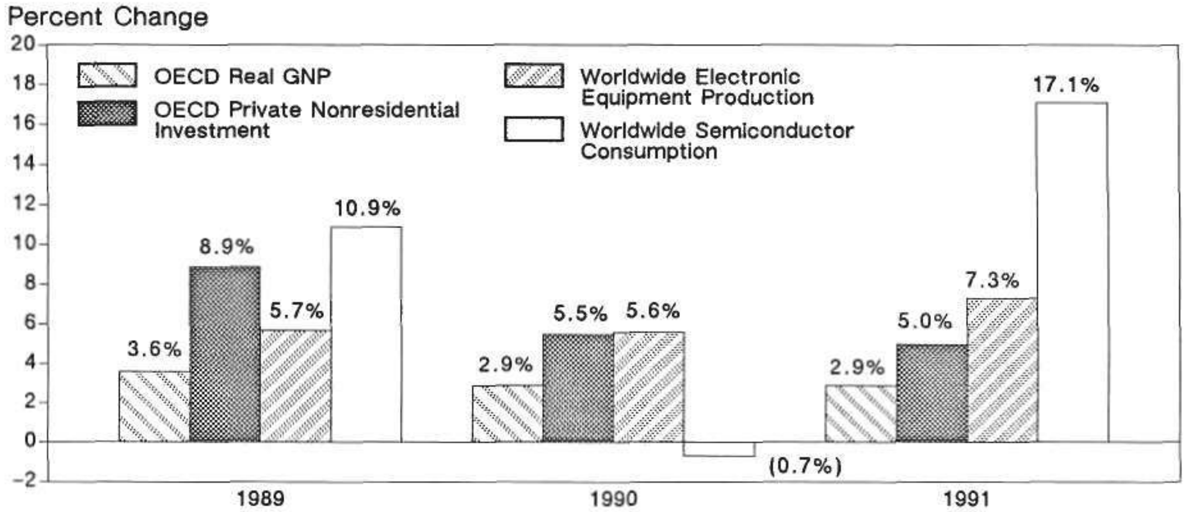
Regional Semiconductor Consumption—1988-1989
(Millions of Dollars)

Region	1988	1989	Percent Share 1989	Growth 1988-1989
North America	$15,844	$17,937	31.4%	13.2%
Japan	20,772	22,997	40.2	10.7%
Europe	8,491	9,755	17.0	14.9%
Asia/ROW	5,752	6,524	11.4	13.4%
Total	$50,859	$57,213	100.0%	12.5%
Annual Growth	33.0%	12.5%		

Note: Excludes captive demand
Source: Dataquest (August 1990)

Figure 5-5

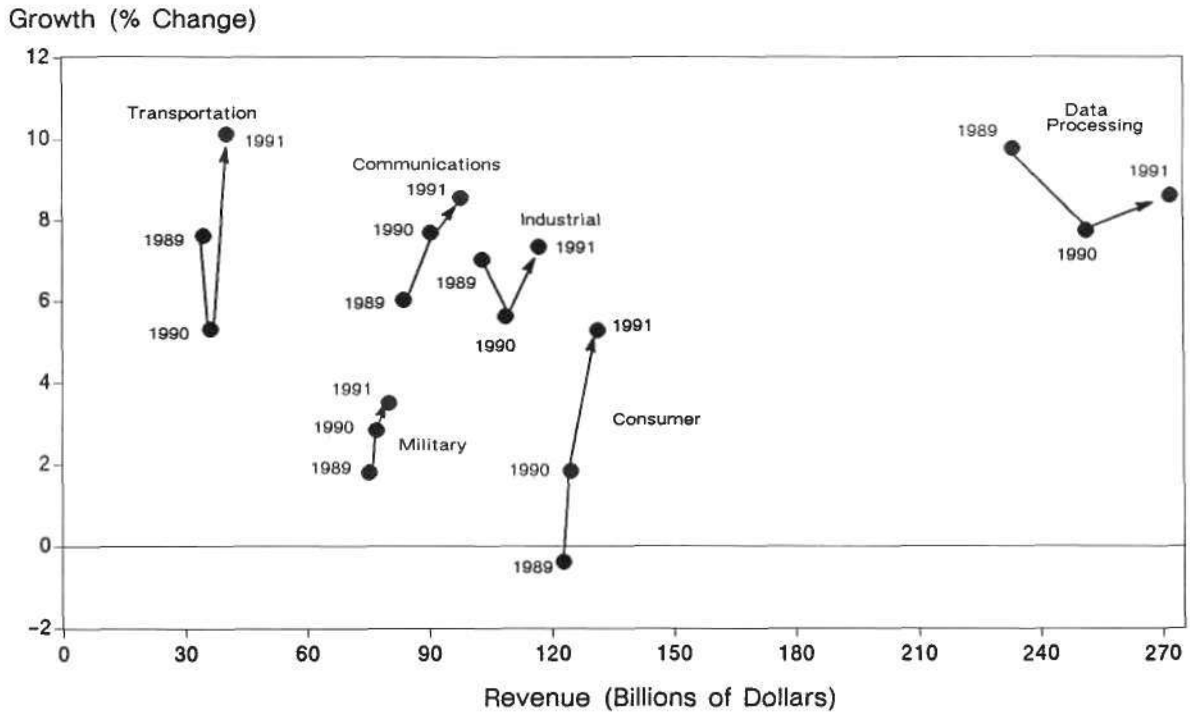
Estimated Changes in Economic, Electronic Equipment Production, and Semiconductor Consumption Growth—1989-1991



Source: Dataquest (August 1990)

Figure 5-6

Growth Trends for Applications Segments—Worldwide



Source: Dataquest (August 1990)

Worldwide Semiconductor Demand Forecast by Product—1990 and 1991

Table 5-5 presents the worldwide demand estimate and forecast by semiconductor product. The total demand CAGR for 1989 through 1991 is 8.0 percent. Total MOS digital ICs are forecast to grow at a CAGR of 9.0 percent from 1989 to 1991, driven by growth in logic, memory, and microcomponent products. In addition, analog IC products are expected to have a CAGR of 9.7 percent for that period. Bipolar memory is forecast to decline steadily through the period as it is replaced by BiCMOS memory for high-performance applications. In general, Table 5-5 shows significant growth across all product areas except bipolar digital ICs from 1989 to 1991 as the industry recovers from two slow growth years. Dataquest expects a 16.5 percent growth rate for the total semiconductor market in 1991.

Worldwide Semiconductor Demand Forecast by Region—1990 and 1991

Table 5-6 presents the 1990 and 1991 forecast and 1989 actual numbers by region. Not surprisingly, the Asia/ROW region is forecast to enjoy the highest growth, with a CAGR of 14.8 percent; Europe should enjoy the next highest growth, with a 13.1 percent CAGR. Japan is forecast to have a CAGR of 5.3 percent, barely behind the North American region's estimated 6.0 percent. Also notice that the Asia/ROW region is expected to enjoy a 23.1 percent growth rate in 1991.

North American Demand Forecast—1990 and 1991

After a slow first half, the semiconductor market in 1990 is expected to show significant growth by year's end, with 4.9 percent and 5.4 percent increases in demand for the third and fourth quarters, respectively. On the whole, Dataquest anticipates a negative 3.1 percent growth rate in 1990. Demand growth will decline to 2.4 percent in the first quarter of 1991, followed by strong 5.2 percent growth in the second quarter. Continued strong growth is expected in the second half of 1991, yielding a 16.2 percent growth rate for the year.

Table 5-7 presents the North American forecast by semiconductor product for 1990 and 1991, along with the actual 1989 numbers. The total North American semiconductor market is expected to grow 16.4 percent in 1990, with a CAGR of 6.0 percent for the period 1989 to 1991. In addition, the total IC market is forecast to grow 17.7 percent in 1990, with a CAGR of 6.2 percent for the 1989 to 1991 period. The dominant influence is, of course, MOS memory, which will drive a 19.7 percent growth in the MOS digital category from 1990 to 1991. After a 5.7 percent decline from 1989 to 1990, the addition of the 1991 growth yields a CAGR of only 6.3 percent for

Table 5-5

Worldwide Semiconductor Consumption by Product—1989-1991 (Millions of Dollars)

	1989	1990	1991	Growth 1990/1991	CAGR 1989-1991
Total Semiconductor	$57,213	$57,265	$66,720	16.5%	8.0%
Total IC	$46,924	$46,543	$54,966	18.1%	8.2%
Bipolar Digital	4,510	4,135	4,427	7.1%	(9.2%)
MOS Digital	33,024	32,549	39,235	20.5%	9.0%
Analog	9,390	9,859	11,304	14.7%	9.7%
Total Discrete plus Optoelectronic	$10,289	$10,722	$11,754	9.6%	6.9%

Note: Excludes captive consumption
Source: Dataquest (August 1990)

Table 5-6

Regional Semiconductor Consumption—1989-1991
(Millions of Dollars)

Region	1989	1990	1991	Percent Share 1989	Percent Share 1991	Growth 1990/1991	CAGR 1989-1991
North America	$17,937	$17,312	$20,154	31.4%	30.2%	16.4%	6.0%
Japan	22,997	22,287	25,498	40.2	38.2	14.4%	5.3%
Europe	9,755	10,678	12,469	17.0	18.7	16.8%	13.1%
Asia/ROW	6,524	6,988	8,599	11.4	12.9	23.1%	14.8%
Total	$57,213	$57,265	$66,720	100.0%	100.0%	16.5%	8.0%
Annual Growth	12.5%	0.1%	16.5%				

Note: Excludes captive consumption
Source: Dataquest (August 1990)

Table 5-7

North American Semiconductor Consumption—1989-1991
(Millions of Dollars)

	1989	1990	1991	Growth 1990/1991	CAGR 1989-1991
Total Semiconductor	$17,937	$17,312	$20,154	16.4%	6.0%
Total IC	$15,909	$15,225	$17,927	17.7%	6.2%
Bipolar Digital	1,701	1,567	1,651	5.4%	(1.5%)
MOS Digital	11,682	11,021	13,190	19.7%	6.4%
Analog	2,526	2,637	3,086	17.0%	10.5%
Total Discrete plus Optoelectronic	$2,028	$2,087	$2,227	6.7%	4.8%

Note: Excludes captive consumption
Source: Dataquest (August 1990)

the 1989 to 1991 period. Also showing substantial demand growth is the market for analog ICs. Demand is expected to grow 17.0 percent in 1991, with a CAGR of 10.5 percent from 1989 to 1991. As is the case in the worldwide market, the demand for bipolar digital ICs shows a general decline throughout the period.

Four Strategic Issues

What Are the Semiconductor Demand Drivers?

The driving force behind the 1990 and 1991 demand forecast (shown in Table 5-5) is MOS memory, particularly DRAMs and SRAMs. DRAM prices have dropped significantly since the first half of 1989, especially for 1Mb devices, but they appear to be stabilizing. Thus, DRAM demand growth in dollar terms is forecast at negative 32.0 percent for 1990 and at positive 28.0 percent for 1991 when measured on a year-to-year basis. Unit growth is forecast at a negative 5.7 percent for 1990.

This forecast is very dependent on DRAM pricing assumptions because, as mentioned earlier, DRAMs make up such a large portion of the product mix. This dependency and the underlying pricing assumptions are discussed in the following paragraphs.

Products within the data processing segment—PCs, technical workstations, graphics workstations, and medium-scale business computers—are driving much of the DRAM/SRAM demand. New applications for MOS memories are emerging that include digital copiers, digital fax machines, digital VCRs, and extended-definition TV (EDTV).

The outlook for microcomponents and MOS logic is significantly different. Because the PC industry is expected to have slower growth during 1990 than in 1989, microprocessor growth should be correspondingly slower, at 6.4 percent in 1990, down from 14.5 percent in 1989 and 14.6 percent in 1991. MOS logic growth is forecast at 8.5 percent in 1990 and 20.5 percent in 1991.

Optoelectronic and discrete devices, primarily used in communications and consumer electronic products, are forecast to have moderate growth. Optoelectronic growth is expected to be 4.0 percent growth in 1990 and 16.1 percent in 1991. Discrete devices are projected to experience a 2.8 percent growth in 1990 and an 11.0 percent growth in 1991.

What Caused the Regional Shift in Worldwide Semiconductor Demand from 1984 through 1989?

The regional demand for semiconductors has changed dramatically over the last four years. A summary of key points follows:

- In 1984, Japan and the Asia/ROW countries represented $11 billion, or only 38 percent of the $29 billion total, whereas North American demand in 1984 was $13 billion for a 45 percent share.
- The 1984 North American demand for electronic equipment constituted 44 percent of the worldwide equipment demand, while Japan and Asia/ROW's share was only 21 percent. By 1989, the North American equipment demand fell to 40 percent, and the Japanese and Asia/ROW share climbed to 27 percent.
- The North American share of electronic production fell much further, as indicated by the decline in semiconductor demand share from 45 percent to 31 percent.

There are three primary causes for this dramatic shift. First, North American equipment producers moved offshore. By 1984, most of the consumer electronics producers had moved their production to Asian sites where the low cost of labor was more favorable to high productivity and competitiveness. Many data processing, communications, and industrial equipment suppliers either had done the same or were having subassemblies manufactured offshore for final assembly and test in North America. This ongoing shift of US equipment production to more favorable economic climates is one obvious cause of the observed shift in semiconductor demand (see Chapters 2 and 4 for further information).

Second, a shakeout occurred among US suppliers. In 1985, a 15.6 percent decline took place in worldwide semiconductor demand, and a precipitous 28.0 percent decline occurred in US demand. Much of the observed shift in regional semiconductor demand occurred in this 1985 and 1986 recession period, which suggests an additional cause for the observed shift.

To find the additional cause requires digging deeper into the events surrounding 1984 through 1986. Chapter 4 identified 1984 as a boom year, particularly for relatively new producers of PCs and related equipment and communications equipment producers. Excessive demand accounted for the apparent success of many of these producers. But when the demand fell off in 1985, their fundamental lack of competitiveness could not withstand the onslaught of Japanese and Asia/ROW competitors in a declining market. As a result, many of these new US equipment producers fell by the wayside rather suddenly during 1985 and 1986.

Any slack in the supply from this shakeout of new US equipment producers was filled quickly by their Asia/ROW and Japanese counterparts. The former US demand for semiconductors suddenly shifted to

Asia and Japan as the "victor's" equipment sales filled the void.

The third primary cause for this dramatic shift in demand share to Japan has been the change in the exchange rate caused by the devaluation of the dollar beginning in 1986. Indexed against the 1984 exchange rate of 237 yen/dollar, the volume in yen of the worldwide semiconductor demand increased only 33 percent from its 1985 level. The Japanese share has increased far less than otherwise observed in terms of current dollars.

As a result of these circumstances, the Asia/ROW region experienced the highest demand CAGR from 1986 to 1989, followed by Japan, Europe, and the United States. Thus, the extraordinary sustained growth in semiconductor demand from 1985 to 1989 was by and large enjoyed in Japan and the Asia/ROW countries, although all regions experienced healthy growth during the period.

What Is the Impact of Regional Economic Conditions on Semiconductor Demand for 1990 and 1991?

The following paragraphs summarize Chapter 3's detailed forecasts of each region's economic climate and Chapter 4's analysis of the impacts of these forecasts on each region's electronic equipment demand and production and relates them to the regional forecast of semiconductor demand given in Table 5-6. For more detailed information, please refer to the appropriate chapter.

North America

The US economy grew 3.0 percent in terms of real GNP in 1989. The real capital spending growth in 1989 was nearly 4.1 percent over 1988 and is forecast to increase slightly less than 4.3 and 4.4 percent for 1989 and 1990, respectively. North American electronic equipment production grew 6.0 percent in 1989. However, because of the slowing of capital spending and reduced competitiveness in export markets, electronic equipment production growth in the United States is projected at 5.8 percent in 1990 before rebounding to 6.4 percent in 1991.

This estimate assumes that the exchange-rate-derived competitiveness of US equipment producers continues to enable them to at least hold their existing market share of export markets in Europe. As the US dollar rises, US electronic exports become less competitive in foreign markets. As 1990 unfolds, US interest rates, labor costs, and inflationary pressures suggest that US fundamental competitiveness will be challenged during the expected period of reduced worldwide market for electronic equipment.

If the US dollar rises very much above 160 yen/dollar and 2 deutsche marks/dollar in 1990, the impact of this effective price increase in Europe and Asia, coupled with higher domestic costs, could invalidate the forecast level of export and thus reduce the actual equipment production to be less than what was forecast.

From Dataquest's estimates of the North American growth of electronic equipment production by application segment, the data processing and communications segments should realize the highest growth over the forecast period, led by PCs and related peripherals, high-performance graphics workstations, and LANs. Growth of the data processing equipment segment is forecast at 7.5 percent for 1990; growth of communications is projected at 7.8 percent.

As expected from the data presented in the previous paragraphs, the North American semiconductor demand's highest segments are data processing, communications, and industrial. However, by far the most influential end product in the North American semiconductor demand forecast is the personal computer.

That the production of PCs is critical to the health of US semiconductor demand is easily appreciated when one considers that PCs alone account for more than 11.0 percent of North American semiconductor consumption. Dataquest's North American semiconductor demand forecast is based on the forecast that the unit quantity of PCs produced in the United States will decline to 8.5 percent growth in 1990 from 1989's 14.3 percent growth rate. Dataquest expects growth of PC unit shipments to increase, posting a growth rate of 9.3 percent in 1991.

Japan

The Japanese economy is strong but slowing, with a 1989 annual growth of 4.8 percent, down from a rate of 5.7 percent in 1988. This growth is expected to decline slightly over the forecast period to 4.5 percent in 1990 and 4.3 percent in 1991. This estimate assumes some decrease in Japanese exports and a continued healthy growth in imports.

The Japanese domestic electronic production growth rate therefore is expected to climb to 1.4 percent in 1990 after a 0.3 percent decline in 1989, followed by 4.9 percent growth in 1991.

The Japanese marketing strategy is to focus its sales of consumer products on its still-buoyant domestic demand while aiming sales of computers, communications, and industrial equipment to export markets.

The requisite export level to sustain the forecast GNP growth assumes that the Japanese economy will continue to sustain historic productivity levels. Japanese competitiveness as an exporter and even as a domestic supplier will be challenged because of the strong yen and increasing costs within Japan. However, many Japanese producers have moved portions of their equipment production offshore to Thailand, Malaysia, and Singapore to reduce costs and assure competitiveness both domestically and worldwide.

Despite challenges to Japanese competitiveness, the primary growth segment of equipment production will be data processing, which is forecast to grow 4.3 percent in dollar terms in 1990 before increasing to 7.2 percent growth in 1991. New applications such as EDTV, point-of-sale (POS) terminals (required by Japanese retailers to handle the new sales tax), and various high-performance consumer products are expected to provide growth in the near fugure.

The forecast decline in Japan's electronic production growth rates is the result of the following:

- The shifting of a portion of Japan's equipment production to the Asia/ROW and European regions
- The reduction of export levels due to the strong yen and the need to balance Japan's trade surplus
- The slowing of demand from the United States and Europe as a result of the forecast global economic "soft landing" in 1990

Japanese semiconductor demand will decline 2 percent in 1990, before experiencing a 16 percent growth in 1991 (see Table 5-6). The reduced 1990 growth in dollar terms is the direct result of declining DRAM prices and reduced electronic equipment growth, resulting from Japanese electronic manufacturing shifts to Asia and Europe.

Europe

The GNP/GDP of the OECD European countries enjoyed moderate 3.5 percent growth in 1989 but is forecast to decrease to 2.8 percent in 1990 and 2.7 percent by 1991. Annual capital spending growth will fall to 5.2 percent in 1990 and decrease slightly to 5.1 percent by 1991. Preparations for the unified 1992 European market will sustain a higher level of electronic equipment demand than would otherwise be expected under the global economic slowdown expected through the forecast period. During the next four years, the European market offers some unique opportunities and challenges. Many local and multinational companies, including those from the United States, Japan, and the Asia/ROW region, are building production facilities in Europe to take advantage of Europe 1992. These facilities will purchase semiconductors locally to receive favorable tax treatment, so additional semiconductor production capacity is building up in Europe as well. Because of this 1992 effect, some additional electronic equipment production and the resultant semiconductor consumption will shift into Europe from the other regions during 1990 and 1991.

PCs were the driving force for European semiconductor demand growth, particularly in MOS microcomponents, memory, and bipolar digital logic. PC production accounts for more than 50.0 percent of Europe's DRAM consumption. Order rates from European PC manufacturers have been low since the middle of 1989 and have continued into the first half of 1990. Despite this decline in IC demand from PC vendors, Europe is forecast to increase semiconductor consumption by 9.5 percent in dollar terms in 1990 (due mainly to exchange rate fluctuations) and to sustain a 16.8 percent growth in 1991.

Asia/ROW

The Asia/ROW countries are forecast to experience a slight decline in real GNP/GDP growth from their historic double-digit growth levels to the 4.5 to 7.5 percent range during 1990 and 1991. Both consumer and capital spending are forecast to remain robust as these economies continue their course of rapid expansion through export. Because North America constitutes a large portion of their export market (40.0 percent), some slowing in exports is expected in 1990, but this could be offset by increased exports to China, Thailand, and other developing countries.

As mentioned previously, the Asia/ROW region also is the beneficiary of much of the Japanese consumer equipment producers' move offshore to sustain competitiveness. A portion of its equipment production growth forecast reflects this shift in production from Japan.

The primary drivers of semiconductor demand in the Asia/ROW region are PC and consumer product production. Recent softness in North American and European PC demand caused semiconductor demand to slow in 1989 and early 1990. Considerable consumer product production growth is forecast over the next two years, as the domestic markets of China and Thailand begin to open up.

Thus, Asia/ROW semiconductor demand is forecast to decline from the 8.9 percent growth rate in 1989 to a 6.1 percent growth rate in 1990 before realizing 24.9 percent growth in 1991.

What Are Price and Availability for Critical Devices?

The key semiconductor devices to be under pressure for price and availability appear to be memory-related: DRAMs and SRAMs. Some concern will exist about price and availability of high-performance 32-bit microprocessors, but with the expected slowdown in the computer industry, it will not be too strong.

Single-source manufacturers of 32-bit MPUs incur large R&D expenses while developing these products and then must pay huge fab costs to produce the chips. Consequently, suppliers of 32-bit MPUs fiercely resist abrupt price declines during the growth stage of the product life cycle (unlike the reality of the semiconductor memory business). Instead, once volume production starts, 32-bit MPU suppliers fight to hold prices relatively high for several quarters or more—at least until a significant portion of new product costs have been recaptured. Product pricing can drop somewhat quickly during the mature stage before stabilizing.

Suppliers of 32-bit MPUs are ramping up output and cutting prices of 20-MHz and 25-MHz products during 1990. Prices for mature 16-MHz products have been more stable. Dataquest expects pricing to edge down for Motorola's 68020 products during 1991. We expect pricing for the 68030 to move sharply at the end of 1990 and the beginning of 1991. In contrast, users of Intel's 80386 products can expect a rather flat product price profile in 1991.

As 1989 progressed, lower orders from equipment producers caused a decline in both unit quantity and ASP growth. Dataquest expects 1Mb DRAM pricing to move downward throughout 1990, although at a slower rate than in late 1989 and the first half of 1990. We anticipate the 4:1 unit/price crossover to 4Mb DRAMs from 1Mb parts to occur in North America during the first quarter of 1991. At that time, Dataquest forecasts that the price of 4Mbx1 devices will be $24.10 and that of the 1Mbx1 will be slightly less than $6.00. The recent cutbacks in 1Mb DRAM production capacity cloud the 1991 DRAM outlook. Even so, most recent surveys indicate that several large and dependable suppliers of 1Mb DRAMs plan to reduce prices throughout the forecast period, reaching a price of slightly less than $4.95 by the fourth quarter of 1991.

CHAPTER 6

Semiconductor Production

In 1989, more than $57 billion worth of semiconductor products were manufactured worldwide. The semiconductor industry supplies billions of individual semiconductor devices to satisfy semiconductor demand generated by worldwide electronic equipment producers. These devices consist of many different types of semiconductor products including diodes, transistors, ICs, and optoelectronic devices.

More than 200 companies throughout the world produce semiconductor devices. These companies range in size, products, and marketing strategies from giant multinational corporations engaged in volume production of commodity ICs to much smaller companies addressing specialized market niches.

Despite their diversity, semiconductor companies share a common purpose: the miniaturization of electronic devices through the use of semiconductor materials. The technology behind this industry involves elements of physics, chemistry, and electronic theory that are at the cutting edge of their respective disciplines.

This chapter describes the underlying forces that influence semiconductor production. The chapter is organized into the following three sections:

- Background—The underlying forces of production are addressed as follows:
  - What are the key characteristics of semiconductor manufacturing?
    - Two-stage process
    - Cost and investment structure
    - High-cost wafer fabs
    - Offshore shift of back-end process
    - Demand for high-volume technology driver
  - Who manufactures semiconductors?
  - Where are semiconductors manufactured?
- Production forecast—1989 and 1990 worldwide and regional production forecast by region and location of company headquarters
- Strategic issues—Key issues and opportunities relating to the semiconductor production forecast

Background

Key Characteristics of Semiconductor Manufacturing

In general, semiconductors are manufactured in two major stages:

- The front-end (wafer fabrication) process
- The back-end (device assembly and test) process

The Front-End or Wafer Fabrication Process

The front-end process is a complex sequence involving hundreds of individual process steps that transform bare silicon wafers to fully fabricated wafers made up of multiple integrated circuits. For example, a state-of-the-art 1Mb DRAM process can have as many as 200 to 300 process steps with 15 or more mask layers.

During the semiconductor manufacturing process, the bare silicon wafer is processed through a repetitive sequence of thin film deposition, photolithographic patterning, and etching steps. A series of masks containing the circuit design information are used to transfer the IC pattern into silicon. The fabrication process is carried out in an extremely clean environment to eliminate defects that would otherwise render the IC nonfunctional. The final IC consists of thousands of transistor devices that are connected together in a specified pattern to perform the desired electrical function. Each processed wafer contains multiple rows of identical IC chips that also are known as die. The wafer can now be diced into individual chips and packaged.

The Back-End or Test-and-Assembly Process

The first part of the back-end process consists of electrically testing the finished wafers to check all the chips for adherence to the circuit functional specifications. The bad chips are dotted with ink and will be rejected from subsequent assembly processing. Next, the wafer is diced and the good chips are separated and assembled in ceramic or plastic packages for connection to the outside board-level circuits. The finished integrated circuit package finally is tested again to check for functional performance before being shipped to the customer.

Equipment and supplies (materials) necessary for semiconductor production are categorized as fron-end and back-end equipment and materials. (For further information about semiconductor manufacturing equipment and materials, see Chapter 7.)

Cost and Investment Structure

The manufacturing cost and investment structure for the semiconductor manufacturing process can be characterized as follows:

- Massive capital investment in wafer fab (front end) capacity
- Considerable labor cost for test and assembly (back-end process)
- Materials costs associated with the procurement of the raw silicon wafers and packages

Manufacturing costs are determined by the variable or per-unit cost in terms of materials and labor cost, and the amortization of the fixed capital investment. The biggest impact is that of the amortization. Thus, true profitability and return on investment are critically dependent on the efficiency of the process, or how many devices can be produced for a given fixed investment cost.

Another way of saying this is the profit and return on investment (ROI) of a semiconductor producer is most dependent on the yield from the manufacturing process. (Yield is the number of saleable devices expressed as a percentage of the total devices produced.) Obviously, the higher the yield, the higher the efficiency, and therefore the higher the profit and ROI.

Manufacturers continually seek to improve yields. Many techniques are used, but such improvements most often are the result of new manufacturing technology. The semiconductor equipment suppliers provide the new technology and therefore are critical contributors to the success of semiconductor producers.

High-Cost Wafer Fabs

Because of the high cost of wafer fabs, the semiconductor manufacturing industry is undergoing structural change. In the past, semiconductor producers typically performed all or most of the production steps themselves. Today, however, some newer companies are separating the device design function from the device fabrication process. Such companies add value through innovative design and customer service as opposed to improved manufacturing.

Among companies that possess manufacturing capabilities, marked differences exist in the number of support functions they integrate into the fab process. Such support functions include fabrication of the packaging in which the devices are assembled, growing and preparing the raw silicon wafers, manufacturing the masks used in the photolithographic process, and other related functions. Larger and older companies such as IBM or TI tend to be more integrated. Smaller and newer companies tend not to perform as many of these functions. Intel, for example, purchases masks, wafers, and packages.

Recently, there has been a proliferation of companies offering semiconductor manufacturing services. These include device design, maskmaking, wafer fabrication (wafer foundries), assembly and packaging, and testing services. These companies make it possible to design, manufacture, and market semiconductors without the huge investment in manufacturing equipment, CAD/CAM equipment, or engineering manpower. They serve the needs of other semiconductor manufacturers and semiconductor users alike.

Another reason for the structural changes described previously is the projected increase in wafer fab productivity. Dataquest estimates that by the year 2000, the if-sold value potential of a modern wafer fab facility will be as high as $670 million. This would seem to limit such investments to only the top few billion-dollar companies and encourage "foundry-for-hire" agreements among many other companies.

Offshore Shift of Back-End Process

Japanese semiconductor producers leveraged their economy's superior productivity characteristics—low interest rates, patient capital, and low-cost, highly skilled labor—and developed a competitive edge on US producers. In response, US semiconductor producers transplanted labor-intensive assembly operations offshore to Asia/ROW countries. Today, it is not unusual for wafers to be fabricated in one country, devices assembled in a second, and final testing and shipping to occur in a third. This mobility within the manufacturing process is made possible by the small size and low weight-per-dollar value of semiconductor devices.

This search for the lowest-cost allocation of production resources has led increasingly more companies to invest in overseas assembly plants. This trend is expected to continue, although it eventually may be slowed by increased automation of the assembly process.

Demand for High-Volume Technology Driver

Dataquest's Semiconductor Equipment and Materials Service (SEMS) estimates that because of their huge production volumes, particularly in MOS DRAMs, Japanese producers have as much as a 70 percent cost advantage over US producers. This advantage has the following two primary sources:

- Japan frequently has brought new products through the development process into the market ahead of the United States. This allows Japanese manufacturers to move down the learning curve and to charge lower prices than US suppliers once the latter enter the market. The only way the United States can catch up is to produce significantly higher volumes.

- Most important is that Japanese producers have a decided advantage over their competition in manufacturing yields. At the heart of the yields issue is the need for leading-edge, high-volume products that can serve as technology drivers that improve yields for all products. Since the early 1980s, MOS DRAMs have served this function for semiconductor producers. The United States lost most of its DRAM market share to the Japanese by 1986. Since then, Japan has exploited its massive DRAM production technology for superior yields and the resultant cost advantages in many other products.

Who Manufactures Semiconductors?

More than 200 semiconductor manufacturers exist throughout the major geographical regions. These companies can be classified as follows:

- Independent manufacturers
- Divisions of major corporations
- Captive manufacturers

The first two of these classifications compete in the worldwide merchant market to supply semiconductor products to electronic equipment producers worldwide. Captive manufacturers supply products only for internal consumption to satisfy a company's own electronic equipment production requirements. It is important to note that the merchant and captive supplier classifications are more of a US notion than a Japanese one. In Japan, most semiconductor production is integrated within larger electronics companies.

As mentioned previously, the search for the lowest manufacturing cost has forced producers to become international in scope, at least in manufacturing. The high capital investment required is creating a restructuring of the type of services and products offered as well.

Independent Manufacturers. Most manufacturing (about 70 percent in the United States) is performed by independent manufacturers. Semiconductor manufacturing and sales constitute the major part of their businesses. Their survival depends on their performance in the semiconductor industry. They have no guaranteed markets or financing. In general, they are aggressive, competitive, and innovative in bringing new technologies to market. Companies in this category include Advanced Micro Devices (AMD), Intel, Motorola, National Semiconductor, and TI.

Divisions of Major Corporations. Many major corporations in the United States, Japan, and Europe have divisions that produce semiconductors. These divisions are distinct from captive producers because they actively sell their devices on the open market (merchant market). Most, but not all, of these companies market at least a small portion of their output to their parent companies. All benefit from the financial resources of the parent, which is a distinct advantage considering the huge capital requirement that characterizes semiconductor production.

In some cases, these companies also have the advantage of a small sheltered market (to the parent) for some of their products. On the other hand, they can suffer from parental management decisions that are not in their best interests or that fail to reflect an understanding of semiconductor business issues.

In Japan, these companies are referred to as integrated. The Japanese companies have skillfully combined the financial strength of the parent company, the integration of device design with end-product design to maximize end-product performance and competitiveness, and the cost benefits of volume-production devices for the merchant market. In Japan, both the integrated semiconductor producer and the parent equipment manufacturer win.

Worldwide examples of semiconductor divisions of major corporations include AT&T, Harris, Hitachi, NCR, Nippon Electric (NEC), Philips, Rockwell, Siemens, Toshiba, and Westinghouse.

Captive Manufacturers. Companies that maintain semiconductor manufacturing facilities for production of devices solely for their own use are referred to as captive manufacturers. As semiconductors become more important to major equipment manufacturing companies, these companies are realizing the value of captive facilities that allow device design to be integrated with final system design, thus maximizing the leverage of the underlying silicon.

Many of these captive facilities provide services and unique devices that are not available in the merchant market. That is, they define device requirements based on final system requirements, then design and make what they cannot buy. Captive manufacturers fulfill semiconductor demand that is not available to the other suppliers to the merchant market.

Examples of captive manufacturers are General Motors, Hewlett-Packard, IBM, and Unisys.

Top Ten Worldwide Semiconductor Manufacturers

Table 6-1 shows the overall ranking of the top ten worldwide semiconductor producers by total 1989 revenue. Figure 6-1 shows the revenue growth from the top ten companies from 1987 through 1989. Several items are noteworthy, including the following:

- The number one producer—NEC—has increased its revenue by nearly 50 percent since 1987.
- Of the top three producers, Toshiba has experienced the highest growth rate since 1987, at 62.8 percent, and has firmly established itself in the number two position.
- None of the US companies in the top ten recorded 1989 growth rates that exceeded the industry average of 12 percent. Motorola was the highest at 9 percent, followed by Intel and TI with growth rates of 3 and 2 percent, respectively. In addition, both TI and Intel slipped one place in the market share rankings, to sixth and eighth, respectively. By contrast, each Japanese manufacturer in the top ten, with the exception of Matsushita, experienced growth rates of at least 10 percent.
- Mitsubishi recorded the highest growth rate, 72.9 percent, of any company in the top ten from 1987 to 1989. In doing so, the company moved from number nine to number seven in two years.
- Two companies in the top ten, Matsushita and Philips, experienced negative growth in 1989.

Another important industry characteristic that is shown in Table 6-1 is that of market concentration, which is illustrated in Figure 6-2. This figure shows that the top 10 companies garnered 55.2 percent market share; the top 25 accounted for more than 80.0 percent of the market. The remaining companies (ranked 26 through 136) accounted for only 18.5 percent of the market.

Company Market Shares by Product Category

The products driving growth in 1989 were MOS DRAMs and SRAMs, MOS microcomponents, and MOS ASICs. Tables 6-2 through 6-8 rank the top ten producers in the following major semiconductor product classifications: total integrated circuit, total bipolar digital, total MOS digital, MOS memory, analog ICs, discretes, and optoelectronics.

The Japanese Example:
The Advantage of Integrated Producers over Independent Producers

Japan's mostly integrated semiconductor producers' rapid rise to dominance over the United States' mostly independent semiconductor producers provides empirical evidence that the Japanese model works best. The Japanese model, however, was very much influenced by the IBM company model, and the IBM model included integrated semiconductor production.

As mentioned in Chapter 5, Japan's national objective was to develop its electronic equipment production to a world-class level. Data processing, consumer, and communications were the chosen market segments. As a strategy, Japan licensed product technologies and manufacturing rights, then leveraged its superior economic competitiveness and manufacturing acumen to gain foreign market share through aggressive pricing.

In 1975, the goal of this strategy became dominance over US semiconductor producers. This entailed the cooperative efforts of the MITI, sources of patient capital, and a variety of large electronic equipment producers that were chosen to participate in the development of the Japanese semiconductor industry as integrated producers.

The semiconductor strategy of the Japanese integrated producers was not dissimilar to their equipment strategy and is outlined as follows:

- Capitalize on the innovations of the independent US producers by obtaining licenses to the technology and/or manufacturing rights as a second source
- Focus on MOS DRAMs as the necessary technology driver
- Advance the technology through simplification, thereby reducing manufacturing costs and increasing quality and reliability. In so doing, leapfrog US independent producers and bring 64K DRAMs to the market ahead of them
- Exploit the advantages provided by Japan's more competitive economic climate and its sheltered environment provided by MITI's protection of the Japanese market, the huge financial resources of the parent companies, and the patience of investment capital, by increasing foreign market share through aggressive pricing

This was devastating to US independent DRAM suppliers. In 1975, 15 US manufacturers supplied nearly all of the worldwide market; by 1986, all but 2 had been shaken out of the market. The remaining 2 retained less than a 25 percent share of the entire memory market by 1987. This happened because the Japanese producers won large shares of the 16K DRAM market through aggressive pricing and superior quality from 1978 through 1980 and were first to market with 64K devices in 1980. In 1982, they announced sampling of the 256K MOS DRAM, and subsequently all but the aforementioned 2 US producers withdrew from DRAM production from 1982 through 1985.

Can US Standalone Semiconductor Producers Survive?

We have presented empirical proof that integrated semiconductor producers have inherent advantages over independent producers. Independents, of course, can argue that only in their environment can the innovations and new products that advance the industry be created and developed, and they may be right. However, at this point, the question is becoming academic and is being replaced with another much more important one: Does the standalone semiconductor producer concept of the United States—a product of the entrepreneurial spirit that is the backbone of the free enterprise system—have long-term viability in view of the superior financial resources, government support, and current market shares of the Japanese integrated producers?

The challenge for the United States is how to quickly devise ways to match the superior resources of the Japanese integrated producers while operating within the boundaries of the free enterprise system.

Table 6-1

Top Ten Worldwide Semiconductor Manufacturers for 1989

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	NEC	4,543	5,015	10%
2	2	Toshiba	4,395	4,930	12%
3	3	Hitachi	3,506	3,974	13%
4	4	Motorola	3,035	3,319	9%
5	6	Fujitsu	2,607	2,963	14%
6	5	Texas Instruments	2,741	2,787	2%
7	8	Mitsubishi	2,312	2,579	12%
8	7	Intel	2,350	2,430	3%
9	9	Matsushita	1,883	1,882	0
10	10	Philips	1,738	1,716	(1%)
		North American Companies	18,586	19,978	7%
		Japanese Companies	15,942	29,809	15%
		European Companies	4,917	5,443	11%
		Asia/ROW Companies	1,414	1,983	40%
		Total World Companies	50,859	57,213	12%

Source: Dataquest (August 1990)

In the MOS digital category (see Table 6-4), the remarkable growth experienced by Samsung, moving from 11th to 9th in the ranking is due to the ramping up of its DRAM production. In MOS memory, Sharp and Intel exchanged rankings, with Sharp moving from 10 to 8, due to Sharp's participation in the DRAM market and Intel's lack of participation.

In general, companies that are strong in MOS memory continued to dominate the market. Figure 6-3 shows the pecentage of revenue attributed to MOS memory for the top five worldwide semiconductor suppliers.

Where Are Semiconductors Produced?

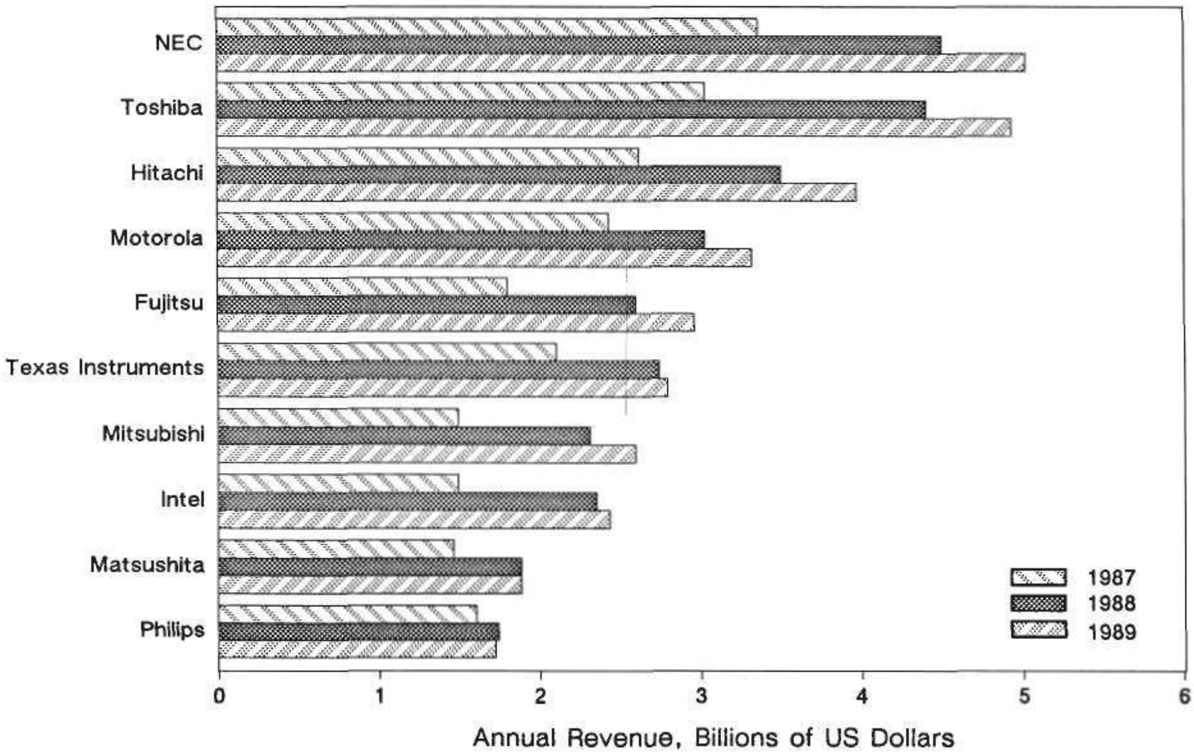
The United States was the semiconductor innovator, and it concentrated on building a dominant industry infrastructure within the country during the early years of industry development. In 1974, the United States controlled an estimated 62 percent of the total world semiconductor market and more than 75 percent of the worldwide IC segment. Including the market represented by US captive producers, the total semiconductor market figure was more than 80 percent.

Through the highly focused efforts of the Japanese integrated producers, initially on DRAMs and subsequently on most other products, the situation looked substantially different by 1990. Figure 6-3 shows that in 1989, the Japan-based companies accounted for more than 52 percent of the total semiconductor market; the share of US-based companies had fallen to 35 percent of the merchant market.

Europe-based companies' share of the world market also declined, from 17.0 percent in 1974 to less than 10.0 percent in 1989, while the share of companies based in Asia/ROW countries captured a 3.5 percent market share in 1989, up from zero in 1980.

Table 6-9 compares the market share of companies based in the United States by major product category in 1980 and 1987. Table 6-10 shows the impact of 1989 growth on these figures and reflects the increasing presence of the Asia/ROW companies in the MOS digital category as the US producers' share continued to decline.

Figure 6-1
Worldwide Semiconductor Market Share
Top 10 Companies—1987-1989
(Billions of Dollars)



Source: Dataquest (August 1990)

Table 6-11 shows the regional semiconductor demand as developed in Chapter 5 and the share of each region's demand supplied by regional company base for 1988 through 1989. As Table 6-11 shows, the US companies' share of the total US demand declined from 70 percent in 1988 to 65 percent in 1989. The Japanese companies' share of US consumption increased from 21 to 26 percent in the same period, while the Asia/ROW countries maintained their 3 percent share.

However, US companies' share of the Japanese market remained relatively constant at approximately 9 percent in 1988 and 1989, while the Japanese companies' share of the Japanese market remained a dominant 90 percent. Japanese and Asia/ROW countries increased their penetration of the European market considerably, from 19 percent in 1988 to 22 percent in 1989.

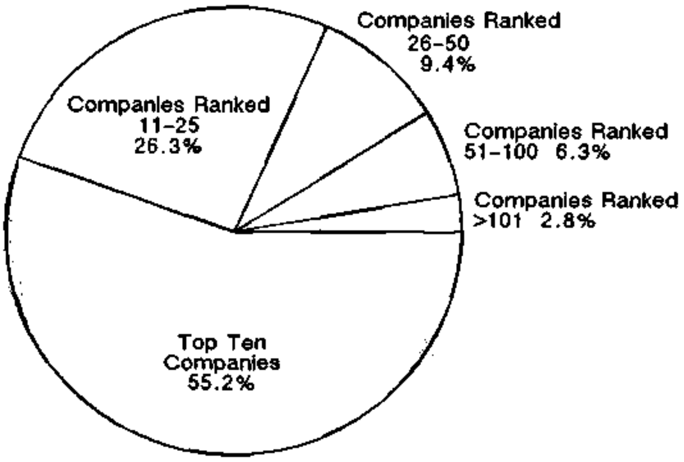
While North American companies' market share in the Asia/ROW region held at 32 percent between 1988 and 1989, the Asia/ROW region increased its market share in their own region. At the same time, Japanese market share fell from 45 percent in 1988 to 41 percent in 1989.

Why the Shift to the Pacific Rim?

Of the numerous reasons for the increased market share of Japanese and Asian producers over the past ten years, the primary one is Japan's focused strategy embodied in its aggressive penetration of the DRAM market, as mentioned previously. Second is the US companies' transfer of large portions of their manufacturing operations to foreign plants. The accompanying technology transfers have then enabled foreign producers to advance these technologies rapidly, thereby diminishing US technical superiority.

Figure 6-2

1989 Worldwide Semiconductor Market Share
Concentration of Revenue



Source: Dataquest (August 1990)

Table 6-2

1989 Worldwide Semiconductor Market Share Ranking
Total Integrated Circuit
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	NEC	3,884	4,321	11%
2	2	Toshiba	3,3163	3,774	14%
3	3	Hitachi	2,729	3,218	18%
4	5	Fujitsu	2,420	2,738	13%
5	4	Texas Instruments	2,637	2,691	2%
6	7	Motorola	2,259	2,519	12%
7	6	Intel	2,350	2,430	3%
8	8	Mitsubishi	1,975	2,185	11%
9	9	National Semiconductor	1,575	1,548	(2%)
10	11	Philips	1,281	1,250	(2%)
		North American Companies	15,990	17,400	9%
		Japanese Companies	20,375	23,800	17%
		European Companies	3,429	3,915	14%
		Asia/ROW Companies	1,274	1,809	42%
		Total World Companies	41,068	46,924	14%

Source: Dataquest (August 1990)

Table 6-3

1989 Worldwide Semiconductor Market Share Ranking
Total Bipolar Digital
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Texas Instruments	940	671	(29%)
2	4	Fujitsu	653	617	(6%)
5	5	Hitachi	501	479	(4%)
4	3	Advanced Micro Devices	536	474	(12%)
3	2	National Semiconductor	550	458	(17%)
6	6	Motorola	435	369	(15%)
7	7	Philips	413	306	(26%)
8	8	NEC	292	302	3%
9	10	Mitsubishi	127	125	(2%)
10	9	Plessey	94	122	30%
		North American Companies	2,761	2,221	(20%)
		Japanese Companies	1,791	1,755	(2%)
		European Companies	598	502	(16%)
		Asia/ROW Companies	50	32	(36%)
		Total World Companies	5,200	4,510	(13%)

Source: Dataquest (August 1990)

Table 6-4

1989 Worldwide Semiconductor Market Share Ranking
Total MOS Digital
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	NEC	3,123	3,604	15%
2	2	Toshiba	2,639	3,100	17%
3	3	Intel	2,328	2,420	4%
4	4	Hitachi	1,885	2,407	28%
5	5	Fujitsu	1,616	1,958	21%
6	7	Motorola	1,399	1,705	22%
7	6	Mitsubishi	1,453	1,676	15%
8	8	Texas Instruments	1,271	1,603	26%
9	11	Samsung	765	1,066	39%
10	10	Oki	841	1,028	22%
		North American Companies	9,754	11,277	16%
		Japanese Companies	14,494	18,006	24%
		European Companies	1,684	2,135	27%
		Asia/ROW Companies	1,056	1,606	52%
		Total World Companies	26,988	33,024	22%

Source: Dataquest (August 1990)

Table 6-5

1989 Worldwide Semiconductor Market Share Ranking
MOS Memory
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	2	Toshiba	1,516	1,918	27%
2	1	NEC	1,490	1,739	17%
3	4	Hitachi	1,114	1,534	38%
4	3	Fujitsu	1,067	1,265	19%
5	5	Mitsubishi	966	1,161	20%
6	6	Texas Instruments	834	1,095	31%
7	7	Samsung	650	935	44%
8	10	Sharp	344	476	38%
9	9	Oki	353	473	34%
10	8	Intel	392	433	10%
		North American Companies	2,836	3,688	30%
		Japanese Companies	7,597	10,558	39%
		European Companies	464	786	69%
		Asia/ROW Companies	795	1,329	67%
		Total World Companies	11,692	16,361	40%

Source: Dataquest (August 1990)

Table 6-6

1989 Worldwide Semiconductor Market Share Ranking
Total Analog Integrated Circuits
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Toshiba	569	572	1%
2	2	National Semiconductor	540	558	3%
3	3	Sanyo	471	530	13%
4	5	Philips	466	522	12%
5	7	Motorola	425	445	5%
6	6	Texas Instruments	426	417	(2%)
7	4	NEC	469	415	(12%)
8	11	SGS-Thomson	352	493	12%
9	9	Mitsubishi	395	384	(3%)
10	8	Matsushita	423	376	(11%)
		North American Companies	3,475	3,902	12%
		Japanese Companies	4,090	4,039	(1%)
		European Companies	1,147	1,278	11%
		Asia/ROW Companies	168	171	2%
		Total World Companies	8,880	9,390	6%

Source: Dataquest (August 1990)

Table 6-7

1989 Worldwide Semiconductor Market Share Ranking
Discrete
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Toshiba	864	848	(2%)
2	2	Motorola	752	775	3%
3	3	Hitachi	707	690	(2%)
4	4	NEC	571	574	1%
5	5	Philips	432	442	2%
6	7	Mitsubishi	310	364	17%
7	5	Matsushita	377	332	(12%)
8	8	Rohm	287	301	5%
9	9	Fuji Electric	279	287	3%
10	10	SGS-Thomson	254	282	11%
		North American Companies	2,171	2,120	(2%)
		Japanese Companies	4,056	4,091	1%
		European Companies	1,250	1,284	3%
		Asia/ROW Companies	135	167	24%
		Total World Companies	7,612	7,662	1%

Source: Dataquest (August 1990)

Table 6-8

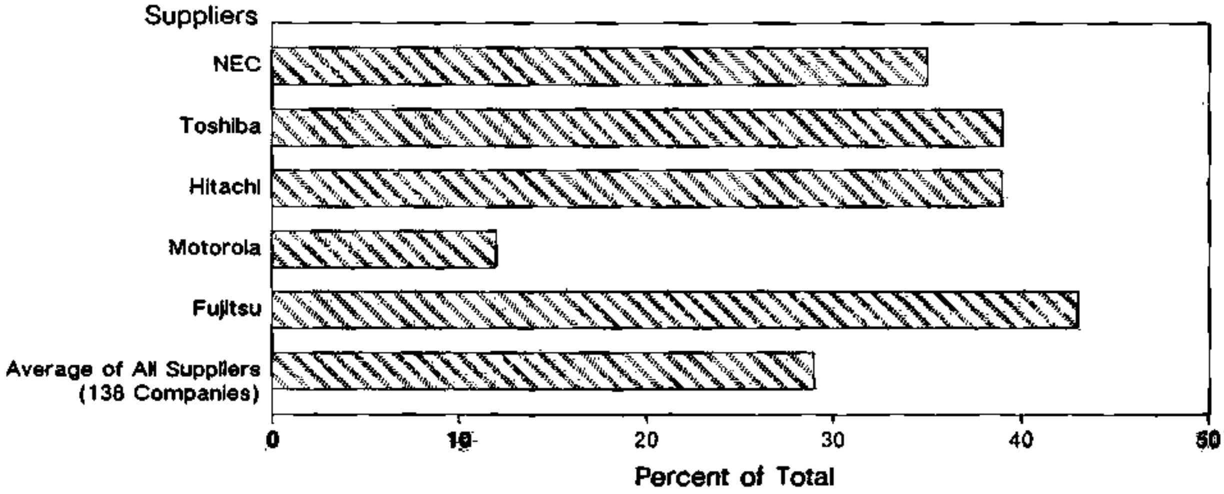
1989 Worldwide Semiconductor Market Share Ranking
Optoelectronic
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Sharp	285	328	15%
2	3	Toshiba	215	308	43%
3	5	Matsushita	178	306	72%
4	2	Sony	217	249	15%
5	4	Hewlett-Packard	213	213	0
6	12	Sanyo	62	160	158%
7	9	NEC	88	120	36%
8	7	Fujitsu	105	116	10%
9	8	Siemens	100	115	15%
10	6	Rohm	109	96	(12%)
		North American Companies	425	458	8%
		Japanese Companies	1,511	1,918	27%
		European Companies	238	244	3%
		Asia/ROW Companies	5	7	40%
		Total World Companies	2,179	2,627	21%

Source: Dataquest (August 1990)

Figure 6-3

Worldwide Semiconductor Market Shares by Company Base



Source: Dataquest (August 1990)

Table 6-9

US Producers' Market Share—1980 and 1987

	1980	1987	Percent Change
Total Semiconductors	57.2%	39.0%	(18.2%)
Total Integrated Circuits	62.7%	42.0%	(20.7%)
Total Bipolar Digital	75.5%	55.0%	(20.5%)
Total MOS Digital	62.3%	41.0%	(21.3%)
MOS Memory	73.7%	28.0%	(45.7%)
Total Analog	46.5%	39.0%	(7.5%)
Total Discrete	43.5%	31.0%	(12.5%)

Source: Dataquest (August 1990)

With the maturation of the industry as reflected by high-volume commodity products, the United States has not had a sufficiently productive economic environment to manufacture commodity semiconductors competitively. Many difficulties also are associated with satisfying the short-term perspective of the US investment community. The constant need to provide a quick return makes it hard for independent US producers to match the manufacturing resources and expertise of Japanese producers that have integrated relationships with large, diversified, and multinational parent companies that allow more favorable economies of scale, lower profit margins, and ready access to more patient capital.

Another basic problem for US chip producers is the rapidly declining US demand for semiconductors (see Chapter 5). This decline, combined with the considerable increase in demand from the Pacific Rim and Japan, is forcing US producers to depend less on domestic consumption of their products and turn toward more effective penetration of these regions.

Table 6-10

US Producers' Market Share—1987 and 1989

	1987	1989	Percent Change
Total Semiconductors	39.0%	34.9%	(4.1%)
Total Integrated Circuits	42.0%	37.1%	(4.9%)
Total Bipolar Digital	55.0%	49.2%	(5.8%)
Total MOS Digital	41.0%	34.1%	(6.9%)
MOS Memory	28.0%	22.5%	(5.5%)
Total Analog	39.0%	42.6%	2.6%
Total Discrete	31.0%	27.7%	(3.3%)

Source: Dataquest

Table 6-11

Worldwide Semiconductor Consumption by Region and Regional Company Share of Production—1988-1989 (Millions of Dollars)

	1988	1989	Market Share 1988	Market Share 1989
Regional Consumption				
North America				
North American Companies	11,146	11,715	70%	65%
Japanese Companies	3,277	4,574	21	26
European Companies	1,006	1,025	6	6
Asia/ROW Companies	415	623	3	3
Total North American Market	15,844	17,937	100%	100%
Japan				
North American Companies	1,965	2,162	9%	9%
Japanese Companies	18,640	20,628	90	90
European Companies	115	130	1	1
Asia/ROW Companies	62	77	0	0
Total Japanese Market	20,772	22,997	100%	100%
Europe				
North American Companies	3,664	4,032	43%	41%
Japanese Companies	1,466	1,924	17	20
European Companies	3,196	3,562	38	37
Asia/ROW Companies	165	237	2	2
Total European Market	8,491	9,755	100%	100%

(Continued)

Table 6-11 (Continued)

Worldwide Semiconductor Consumption by Region and
Regional Company Share of Production—1988-1989
(Millions of Dollars)

	1988	1989	Market Share 1988	Market Share 1989
Asia/ROW				
North American Companies	1,811	2,069	32%	32%
Japanese Companies	2,569	2,683	45	41
European Companies	600	726	10	11
Asia/ROW Companies	772	1,046	13	16
Total Asia/ROW Market	5,752	6,524	100%	100%
Worldwide Production				
North American Companies	18,586	19,978	37%	35%
Japanese Companies	25,942	29,809	51	52
European Companies	4,917	5,443	9	10
Asia/ROW Companies	1,414	1,983	3	3
Total Worldwide Market	50,859	57,213	100%	100%
Annual Growth Rate	31.9%	12.5%		

Notes: Some columns may not add to totals shown because of rounding.
Merchant sales only
Source: Dataquest (August 1990)

To the extent that historic barriers to penetrating these regional markets militate against successful US competition in these regions, US producers and the US government need to cooperate more closely to level the playing field. However, this need must be balanced against the adverse aspects of protectionist legislation. In striking this balance, care must also be taken not to blame an unlevel field for lost market share that is more the result of fundamental noncompetitiveness than trade barriers.

Semiconductor Production Forecast—1990 and 1991

Regional Companies' Semiconductor Forecast—1990 and 1991

The 1990 and 1991 forecast for semiconductor production by regional company base is shown in Table 6-12. This forecast includes captive production. Dataquest forecasts that the demand slowdown discussed in Chapter 5 will cause total production—including captives—to decline by 0.5 percent in 1990, but rebound to grow 16.9 percent in 1991.

Table 6-12 shows the stabilization of North American companies' share of worldwide merchant and captive production. After slowly eroding throughout the 1980s, indications now show that this erosion is slowing. Between 1989 and 1991, US producers have a forecast CAGR of 7.3 percent. Their share of total production during the period 1989 through 1991 will remain the same at approximately 39 percent.

On the other hand, Japanese companies' share of total production is projected to decline from 47.8 percent in 1989 to 44.8 percent in 1991. Most of this decline can be attributed to price erosion in MOS memories. For the same reason, Japanese companies' total output is forecast at a CAGR of only 4.3 percent through the forecast period.

Table 6-12

Worldwide Semiconductor Production Forecast
Regional Company Share—1989-1991
(Millions of Dollars)

	1989	1990	1991	Production Share 1989	Production Share 1991	CAGR 1989-1991
Worldwide Production						
North American Companies	24,044	23.586	27,707	39.8%	39.4%	7.3%
Japanese Companies	28,930	28,093	31,489	47.8	44.8	4.3%
European Companies	5,468	5,868	7,199	9.0	10.2	14.7%
Asia/ROW Companies	2,038	2,613	3,952	3.4	5.6	39.3%
Total Worldwide Market	60,480	60,160	70,347	100.0%	100.0%	100.0%
Annual Growth Rate	10.9%	(0.5%)	16.9%			

Note: Includes captive production
Source: Dataquest (August 1990)

Regional Production Regardless of Manufacturers' Home Base—1989 through 1992

The production forecast of companies headquartered in each of the four regions was given in the previous subsection. However, it also has been indicated that many companies are moving their production facilities to other regions to avoid trade barriers, achieve lowest assembly cost, and get closer to the demand. Examples of this are the fab facilities owned by US and Japanese companies being built in Asian countries such as Singapore and Thailand, and Japanese facilities being built in Europe and the United States.

Therefore, the true semiconductor production within a given region is the total production within the borders of the region, regardless of the home base of the producer. It is this production level that establishes the capital spending within a region and thus establishes the total regional available market for semiconductor manufacturing equipment and materials.

Figure 6-4 shows Dataquest's estimate of such regional semiconductor production from 1989 through 1991. Table 6-13 compares the 1984 regional production share with the 1991 production share forecast. The table shows that despite the increase of Japanese and European fabs in North America, the region's share of worldwide semiconductor production will fall to approximately 35 percent in 1991, much less than the 49.8 percent share enjoyed in 1984, and significantly less than the 45.0 percent of total production from within Japan's borders.

Four Strategic Issues Regarding the Semiconductor Production Forecast

Impact of Regional Imbalances

Table 6-14 compares the total semiconductor demand (including that of captives) by region with the regional production regardless of regional company base (including captives) for 1986, 1989, and 1991. As the table indicates, the difference between production and demand is net exports. The following conclusions can be drawn from the table:

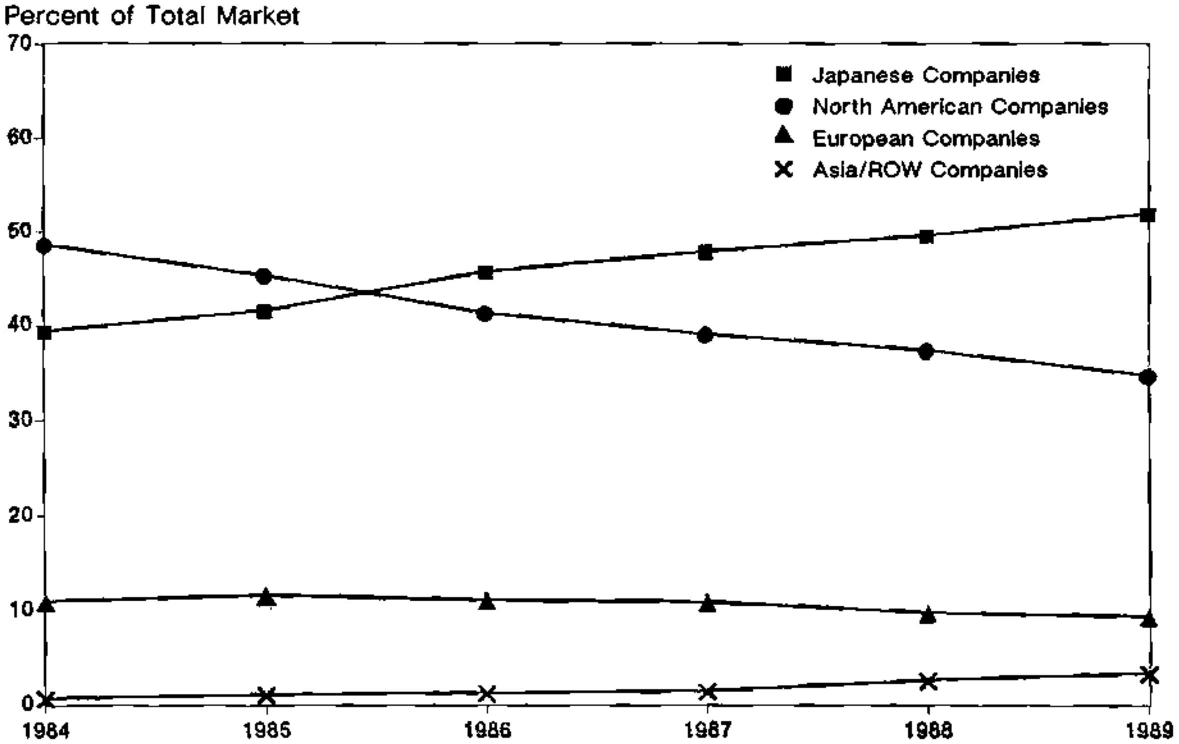
- As a result of preparations for 1992, Europe is substantially increasing its ratio of production to demand, so European producers' share of the European demand is expected to increase from 63.9 percent in 1989 to 80.8 percent in 1991.

- Japan is reversing the historical trend of increasing its ratio of Japanese production to Japanese demand. This ratio peaked in 1989 at 127 percent and should decline to 120 percent by 1990. This again is attributed mostly to MOS memory price declines, but is also because of the increasing share of the European demand being supplied by European companies.

- Asia/ROW companies' share of their own market is forecast to increase from 29.7 percent in 1986 to 52.1 percent by 1990.
- The major export opportunities for the US companies are the Asian ROW and European markets. The combined demand is forecast to more than double between 1990 and 1993. It is critical that US producers increase their share of both markets for their forecast level of production to be realized. It is also critical that the exchange rate of the dollar against the yen and deutsche mark remain at or below today's levels (less than 160 yen/dollar and 2 deutsche marks/dollar)

Figure 6-4

Worldwide Semiconductor Production by Region Regardless of Producers' Home Region



Source: Dataquest (August 1990)

Table 6-13

Worldwide Semiconductor Production by Region

	1984	1991
North America	49.8%	35.1%
Japan	38.3	45.0
Europe/ROW	11.9	19.9
Total	100.0%	100.0%

Source: Dataquest (August 1990)

Table 6-14

Regional Imbalances in Electronic Equipment Demand and Production—1986, 1989, 1991

Region	Demand Millions of Dollars	Demand Percent	Net Exports Millions of Dollars	Production Millions of Dollars	Production Percent	Ratio of Production to Demand
1986						
North America	13,171	39.0%	1,285	14,456	42.9%	109.8%
Europe	5,992	17.8	(2,161)	3,831	11.4	63.9%
Japan	12,018	35.6	2,668	14,686	43.5	122.2%
Asia/ROW	2,548	7.6	(1,792)	756	2.2	29.7%
	33,729	100.0%	0	33,729	100.0%	
1989						
North America	20,978	34.7%	780	21,758	36.0%	103.7%
Europe	10,105	16.7	(3,313)	6,792	11.2	67.2%
Japan	23,134	38.3	6,253	29,387	48.6	127.0%
Asia/ROW	6,263	10.3	(3,720)	2,543	4.2	40.6%
	60,480	100.0%	0	60,480	100.0%	
1991						
North America	23,785	33.8%	887	24,672	35.1%	103.7%
Europe	12,042	17.1	(2,307)	9,735	13.8	80.8%
Japan	26,318	37.4	5,346	31,664	45.0	120.3%
Asia/ROW	8,202	11.7	(3,926)	4,276	6.1	52.1%
	70,347	100.0%	0	70,347	100.0%	

Note: Includes captive production
Source: Dataquest (August 1990)

Opportunities for Semiconductor Producers

Based on the patterns of electronic equipment demand (and therefore, that of semiconductor product categories) outlined in Chapters 4 and 5, the following are the most interesting new product opportunities for the next few years:

- ASICs
- Specialty memories and ferroelectric RAMs (FERRAMs)
- Intelligent power devices
- Microcomponents

ASICs

Although still relatively small today, the ASIC market is forecast by Dataquest to grow at a CAGR of nearly 19 percent through 1993, at which time it should reach sales of more than $15 billion. This forecast is based on the projected growth of the data processing and communications equipment segments, in which most ASICs are used.

Six years ago, the ASIC market was dominated by US producers. Even so, of the top five ASIC suppliers in 1983, Fujitsu ranked as the leader, with slightly more than $100 million in sales, capturing slightly less than one-third of the total market. In 1989, however, three Japanese companies, Fujitsu, NEC, and Toshiba, with Fujitsu remaining the market leader, ranked in the top five, with LSI Logic and AMD positioned at third and fifth, respectively, rounding out the top five.

A large part of Japanese ASIC production is consumed by the supplier's parent company and therefore is not available to independent producers. However, the volume and experience gained through the resulting volume production for internal consumption will propel these companies into merchant market dominance.

Much debate occurs as to the relative merits of ASICs as a technology driver versus those of the traditional DRAMs. Dataquest believes that DRAMs remain the best vehicle for advancing the absolute limits of line geometry. Memory production provides the best "test pattern" for ensuring the highest levels of productivity and reliability in fab equipment. This relationship between memories, process manufacturability, and fab equipment is paramount in the development of new semiconductor technologies.

FERRAMs and Specialty Memories

Niche memory markets, such as those for FERRAMs or other specialty memories, are providing opportunities for small to medium-size companies. These markets are small, highly specialized, and require less capital investment to penetrate than their huge MOS DRAM/SRAM counterparts.

FERRAMs. FERRAMs are memory devices made from ferroelectric material that essentially merges the benefits of volatile and nonvolatile memory. Ferroelectric material allows the stored information to remain in storage when the power is removed. In volume production, such devices could be less expensive and faster than EEPROMs; their success could displace EEPROM demand.

Dataquest estimates that between 1992 and 1995, FERRAMs will have the potential to capture more than 50 percent of the demand for EEPROMs and therefore constitute a nearly $400 million market.

Specialty Memories. Specialty memories are a specific product category within the general memory segment that Dataquest defines as dual-port RAM, FIFO SRAM, and some other small-volume memory devices. The aggregate market for these memories—more than $103 million in 1989—is forecast to exceed $145 million in 1990 and $238 million by 1992. This growth represents a 1989 through 1992 CAGR of 32.2 percent, which is higher than that for the MOS memory segment as a whole—12.1 percent. Although these markets do not offer the tremendous sales volumes that more traditional memory products enjoy, they do offer significant niche market opportunities for the start-up semiconductor company.

Intelligent Power Devices

Intelligent power devices have been among the fastest-growing segments of the analog product category and have been produced mostly by US companies. Dataquest forecasts that the US benefits from this high-growth area may be short-lived, however, as the dominant consumers of analog and smart power devices increasingly are becoming consumer equipment producers. Because this equipment segment is dominated by Asia/ROW and Japanese equipment producers, Japanese companies that heretofore have stayed away from such analog products should be in a good position to enter this market successfully. Dataquest also notes that US analog producers have as of this date been markedly unsuccessful in selling to Japanese consumer electronics producers.

Microcomponents

The leadership in microprocessors, microperipherals, and microcontrollers always has belonged to the United States. However, at the low end of both the microcontroller and microprocessor segments, the Japanese producers are making strong inroads. For instance, the 8-bit microcontroller market, now dominated by the United States, is expected to fall to Japanese producers because of their expertise in CMOS volume manufacturing and their ability to develop a broad portfolio of specialized products.

In the 16- and 32-bit microprocessor arena, the United States is expected to remain dominant at the high-performance end of the spectrum. However, as the trend toward RISC architecture accelerates, opportunity presents itself for the Japanese to gain entry and position with a unique design.

The strongest semiconductor market position that the United States can claim is in this high-end, 32-bit MPU segment. It is critical to the US semiconductor and equipment industries that the United States retain its leadership in such proprietary developments, along with the associated peripheral and support devices.

Capital Spending and Access to Capital Funds

The battle for market share of the total semiconductor demand between regional companies has more importance than receiving a greater share of total revenue in any given year. For US companies that must operate in the highly unforgiving financial environment of the US investment community, market share is the fountainhead of reinvestment. Ultimately, access to investment capital to fund research and development and capital equipment for improving yields or expanding capacity is the lifeblood of long-term survival. Unfortunately, access to requisite investment capital depends more on stellar short-term profit performance in the eyes of the US investment community than on positioning for long-term growth and viability. A key question regarding the future of the US semiconductor industry is whether or not it can obtain the funds to keep up with Japanese capital spending. In dollar terms, the US companies have not kept up with the Japanese companies since the early 1980s. In yen terms, however, Japanese spending actually is at parity with the spending of US companies.

The Dataquest forecast for regional capital spending by region is shown in Table 6-15. The expected Japanese spending levels exceed those of the United States (in dollars) by almost 50 percent through the forecast period. Thus, Japanese companies had a larger 1989 base of semiconductor production capacity than US companies, and they are adding to that base at a faster pace.

Expenditure by the worldwide semiconductor producers on semiconductor equipment is represented by the capital spending forecast in Table 6-15. This becomes the total available market for the semiconductor manufacturing equipment producers. This demand and corresponding supply of semiconductor manufacturing equipment is the subject of the next chapter.

Avoidance of Government Intervention in Free Trade

The semiconductor production forecast assumes that the dollar exchange rates remain favorable for US exports of both electronic equipment and semiconductor devices. It further assumes that natural market forces will remain in effect and that historical trade barriers to Taiwanese, South Korean, and other Asian markets will be lowered. A critical assumption is that of a more favorable balance of trade between the United States and Japan. The objectives of the US-Japan Semiconductor Trade Arrangement of 1986—20 percent penetration of the Japanese market by US semiconductor producers—probably will take several years at its present rate to reach 20 percent share in Japan. In any case, more positive efforts to open the Japanese market must come forth to avoid US government intervention and the associated disruption of the natural market forces upon which the forecast is based.

Table 6-15

**Worldwide Semiconductor Production
Regional Capital Spending—1988-1990
(Millions of Dollars)**

				Market Share		CAGR
	1988	1989	1990	1988	1990	1988-1990
Worldwide Capital Spending						
US Companies	$3,339	$ 3,605	$ 3,677	35.8%	35.7%	4.9%
Japanese Companies	4,587	5,183	4,820	49.2	46.8	2.5%
European Companies	926	1,065	1,139	9.9	11.1	10.9%
ROW Companies	468	545	655	5.0	6.4	18.3%
Total Worldwide Spending	$9,320	$10,398	$10,291	100.0%	100.0%	5.1%
Annual Growth Rate	51.9%	11.6%	(1.0%)			
Capital Spending as Percent of Total Production	17.2%	17.5%	17.0%			

Note: Includes captive production
Source: Dataquest (August 1990)

CHAPTER 7

Semiconductor Equipment and Materials

Preceding chapters have discussed the electronics industry infrastructure in terms of a waterfall of demand. The waterfall starts with the demand for electronic equipment, continues with the demand for semiconductor devices, and ends with the demand for semiconductor equipment and materials (see Figure 7-1).

Semiconductor equipment manufacturers and semiconductor materials suppliers are positioned at the bottom tier of the waterfall, as they are the suppliers to the semiconductor manufacturers and the origin of the upstream flow of technology.

This upstream flow of technology creates the higher-performance and lower-cost semiconductor devices that result in superior electronic products. In fact, world leadership in the $653 billion electronic equipment industry requires world leadership in the $54 billion(merchant and captive) semiconductor industry, which in turn depends on world leadership in the relatively small $6 billion front-end equipment market. It is estimated that semiconductor materials represented approximately a $5 billion market in 1989; so together, equipment and materials accounted for over $11 billion.

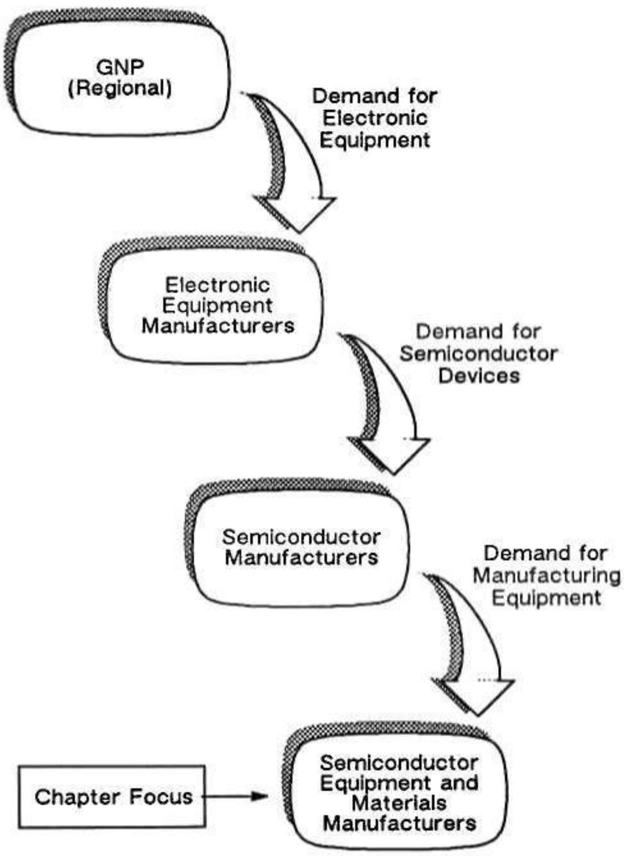
As the preceding chapters have stated, dependency on the source of technology that drives advancing functionality and lower-cost electronic products is so great that regional dominance of specific components of this relatively small industry virtually guarantees regional dominance of the upper tiers of the electronics industry infrastructure.

This chapter is organized into the following subsections:

- Background
  - Discussion of the underlying forces that have created demand for semiconductor equipment and materials
- Key semiconductor materials
- Semiconductor equipment
  - Semiconductor equipment product overview
  - Sources of semiconductor equipment demand
  - Semiconductor equipment demand history and forecast
  - Strategic issues facing the semiconductor equipment industry

Figure 7-1

Demand Waterfall



Source: Dataquest (August 1990)

Background—Semiconductor Equipment and Materials

Although semiconductor equipment and materials are grouped together in this subsection for discussion, it is important to note that semiconductor equipment demand reflects the capital spending budget of the semiconductor producer, while demand for materials is derived from manufacturing cost. Worldwide and regional demand for equipment thus is determined by the worldwide and regional needs for producers to either implement new technology or expand capacity. As a capital expense, such demand often is modulated by the producers' access to investment capital or the cost of such capital. Regional materials demand is more a function of pure semiconductor production levels within each region. In spite of the different budgets, expenditure, or demand for both equipment and materials within any given region, both depend on and contribute to the success and growth of the semiconductor producers within that region and worldwide.

As Chapter 6 pointed out, the success and growth of semiconductor producers within a region depends on the relative competitiveness of these producers and their corresponding ability to capture share of domestic semiconductor demand as well as that of other regions.

Key Semiconductor Materials

A variety of materials are used throughout the various processing steps of front-end wafer fabrication. These materials include wafer substrates such as silicon and gallium arsenide wafers, photoresist and its corresponding ancillary products, bulk and specialty gases, wet chemicals such as sulfuric acid and hydrogen peroxide, deionized water, metal-source targets for sputtering applications, dielectric coatings such as spin-on glass and polyimides, and liquid and solid dopant sources. This part of our discussion will focus briefly on the products, suppliers, and factors that characterize the markets of three of the key materials used in the manufacture of semiconductor devices: silicon wafers, photoresist, and semiconductor gases.

Silicon

Silicon is the second most abundant element in the earth's crust. It occurs in the form of oxides, or silicates such as silica (sand). In the 1950s, silicon was considered to be one of several materials with semiconductor potential. With the development of planar processing in 1960, polysilicon price reductions, and inexpensive plastic silicon transistor packaging, silicon superseded germanium in the market and today is the dominant substrate used in semiconductor device manufacture. As such, it is an excellent indicator of the level of manufacturing activity within a given wafer fabrication environment.

Products

Silicon wafers are thin slices of single-crystal silicon cut from a cylindrical ingot and then polished. The growth of a single-crystal ingot from polycrystalline silicon is controlled to produce wafers with a well-defined diameter, typically 3 to 8 inches.

A second category of silicon wafers is epitaxial wafers. Epitaxial processing produces a layer of single-crystal material that has the same crystallographic orientation as the underlying wafer substrate. It is possible to design the epitaxial layer to meet well-defined chemical, physical, and electrical specifications.

Dataquest estimates that the world merchant silicon and epitaxial wafer market was $2.3 billion in 1989.

Silicon Suppliers

Companies that produce silicon and epitaxial wafers are defined either as merchant silicon companies or captive silicon producers.

Merchant Silicon Companies. The vast majority of silicon consumed today is provided by merchant silicon suppliers. It is interesting to note that all major merchant silicon companies in the world today have large corporate parents. This provides a cash flow buffer against downturns in the business cycle, as well as a source of funding for new facilities and capacity expansions. In today's competitive business environment, it is unclear whether or not a standalone entrepreneurial silicon operation could compete and survive against the major silicon suppliers with their extensive financial backing from corporate parents.

Captive Silicon Producers. Silicon also is produced to a lesser extent by both merchant and captive semiconductor manufacturers. These semiconductor manufacturers are referred to collectively as captive silicon producers because they grow single-crystal silicon to produce wafers for their own internal consumption.

Semiconductor manufacturers with captive silicon production tend to be established, vertically integrated companies. In the early years of the semiconductor industry, the high cost of silicon provided sufficient economic justification for some semiconductor manufacturers to develop this internal capability. Today, however, high-quality, low-cost silicon wafers are readily available from a number of merchant silicon companies. Nevertheless, one benefit of retaining captive silicon production activities is that a semiconductor company can manufacture wafers with custom and proprietary specifications. In addition, captive silicon producers in the United States can ship silicon material to their facilities in Japan and Europe, thereby avoiding those regions' relatively higher wafer costs resulting from currency appreciation over the last several years.

Factors that Characterize the Silicon Wafer Industry

Two significant factors characterize the silicon wafer industry of the last several years. These factors are wafer pricing pressures and industry consolidation.

Wafer Pricing Pressures. Dataquest believes that wafer pricing pressure has been one of the major factors that has affected profitability in the silicon industry during the last several years. Historically, as large wafer products mature, prices decrease because silicon wafer companies move down the learning curve of wafer manufacturing. Pricing has been an important competitive issue as well.

During the downturn of the business cycle between 1985 and 1987, however, there were additional pressures from cost-conscious semiconductor manufacturers for lower prices. At the same time, increasing device complexity led to demands for tighter wafer specifications. This, in turn, meant that silicon companies have had to perform more analytical tests to ensure wafer quality. More analytical testing and product qualification mean higher costs to the silicon companies, and, with the continued downward pricing pressures, silicon companies have been forced to accept smaller margins on their products.

During the healthy market environment of 1988, merchant silicon companies experienced some relief from the downward pricing pressures of previous years. This trend has allowed some silicon companies to return to profitability after several years of losses. Dataquest believes that a favorable and stable wafer pricing environment is essential in order to avoid severe profitability problems in the silicon wafer industry in the future.

Industry Consolidation. A series of eight acquisitions of merchant silicon and epitaxial wafer companies has occurred since 1985 (see Table 7-1). In the majority of these acquisitions, the new corporate parent was already active in the silicon wafer industry prior to its acquisition of its new silicon company. These acquisitions illustrate the dynamics of consolidation in a maturing industry.

As seen in Table 7-1, seven of the eight acquisitions consisted of US silicon companies being acquired by Japanese or West German corporations. The two most recent acquisitions, in particular, had a significant impact on the worldwide market share of US-based silicon suppliers by reducing their share to less than 1 percent of the worldwide merchant silicon market. This situation has raised several important concerns. With the United States' loss of all control over the production of merchant silicon wafers, are its semiconductor manufacturers at a disadvantage in the development of next-generation integrated circuits? Will silicon operations under foreign ownership be fully responsive to the needs of US semiconductor manufacturers?

Clearly, other countries already have decided that silicon is a crucial strategic material. Most of the new entrants in the merchant silicon wafer market over the last several years have come from outside the United States—notably from Japan, Europe, and the Pacific Rim. In these countries, the short-term rigors of the silicon wafer market are endured as part of a long-term strategy for survival in the electronics industry.

Photoresist

Photoresist is a light-sensitive, polymer-based material applied to wafers during semiconductor fabrication to transfer the circuit pattern from a mask to the underlying substrate. Photoresist is applied to the wafer at every mask level during the fabrication process; the number of mask levels correlates with device complexity.

Table 7-1

Recent Acquisitions in the Silicon Wafer Industry

Acquisition Announced	Company	Acquired By
1990	Union Carbide Polysilicon (US)	Komatsu Electronic Metals (Japan)
1989	IBM Silicon Wafer Operation (US)	Huels/MEMC (West Germany
1988	Monsanto Electronic Materials Company (US)	Huels AG (West Germany)
1988	Cincinnati Milacron (US)	Osaka Titanium Co. (Japan)
1987	Dynamit Nobel Silicon (Italy)	Huels AG (West Germany)
1986	US Semiconductor (US)	Osaka Titanium Co. (Japan)
1986	Siltec Corporation (US)	Mitsubishi Metal (Japan)
1985	NBK Corporation (US)	Kawasaki Steel (Japan)

Source: Dataquest (August 1990)

Products

Resists used in semiconductor device fabrication typically are classified into four different categories that reflect the sensitivity of the resist to a given type of light or radiation. The four categories are optical, deep-UV, e-beam, and X-ray resists.

Resists are characterized as positive- or negative-working materials. The basic difference between a positive and a negative resist depends on the material's response to light or radiation. A positive resist leaves behind an image on the wafer that matches the pattern on a mask, while a negative resist leaves behind an image that is the reverse of the mask pattern.

In addition to the resist material itself, there is an associated class of chemicals known as resist ancillary products. These include developers, rinses, dyes, strippers, thinners, adhesion promoters, and etchants. The developers, in particular, are closely designed to complement a given resist formulation in order to optimize resist performance.

Almost all resist materials used in semiconductor device fabrication today are optical photoresists. Dataquest estimates that the 1989 world market for optical photoresist was approximately $265 million.

Photoresist Suppliers

Typically, photoresist companies are part of larger chemical or electronic materials corporations. Four major companies dominate the world's optical photoresist market today: One is Japan-based, two are US-based, and one is Europe-based. The major Japanese photoresist supplier historically has focused on its home market of Japan. In contrast, the two major US suppliers and the major European photoresist company have a well-established presence in all three of the major processing regions of the world: Japan, the United States, and Europe. This has been achieved through overseas photoresist operations (including manufacturing plants) and joint ventures.

Export Market Strategies. Dataquest has observed that when Japanese semiconductor manufacturers set up new fab facilities outside of Japan, often these new fabs are designed to duplicate an existing line in Japan. These include not only products and process technology, but also fabrication equipment and semiconductor materials. This strategy allows the semiconductor manufacturer to bring the new fab line up to speed in a very short period of time.

This practice has particular significance for Japanese photoresist suppliers, which historically have had only minimal participation in export markets such as the United States or Europe. Because photoresist is such a complex chemical system, Dataquest believes that it will be a high priority with Japanese semiconductor manufacturers to use the same resist for their new fab facilities outside of Japan as in their current fabs in Japan. Therefore, Japanese resist companies now have a well-defined avenue to expand their export market opportunities.

Factors that Characterize the Photoresist Industry

Several factors and issues characterize today's photoresist industry, including the following:

- Photoresist is closely tied to lithography, the technology driver for manufacturing higher-density integrated circuits.
  - As semiconductor manufacturers continue to push the limits of submicron processing, it is clear that the lithography process must be considered as a single system. This system includes the device process technology, the lithography equipment, lenses, and sources, as well as the photoresist material itself.
  - Dataquest believes that joint development and exchange programs between semiconductor companies, equipment vendors, and photoresist manufacturers will be essential in the development of advanced submicron processes.
- One of the major issues facing semiconductor manufacturers today is to determine what strategy will be adopted for 0.5-micron device processing expected in production in the mid-1990s.
  - Currently, several lithography alternatives exist including g-line steppers, i-line steppers, excimer laser steppers, step-and-scan lithography, or X-ray lithography. Right now, however, there is no clear consensus of opinion.
  - For photoresist manufacturers, this also is a key issue because few companies have sufficient R&D funds to develop new resist formulations for all lithographic alternatives. Photoresist companies today are faced with deciding where to focus their R&D efforts, ever mindful that different regional semiconductor manufacturers may well pursue different lithography strategies.
- Photoresist is perceived by the customer to be a technology-driven product because the material's performance is closely tied to lithography processing.
  - Therefore, photoresist suppliers have not experienced the same level of downward pricing pressure as in other electronic material categories.
  - Pricing—for optical positive resist, in particular—has remained fairly stable or experienced a modest increase as new resist formulations are developed for the processing of smaller line geometries.

Semiconductor Gases

Products

Semiconductor gases generally are divided into two product categories: bulk and specialty gases.

Bulk Gases. The bulk semiconductor gases are nitrogen, oxygen, hydrogen, and argon. The "bulk" designation typically refers to a discrete delivery of a large volume of gas by truck transport. These gases typically are delivered as cryogenic liquids because of the efficiency of transportation and storage prior to the vaporization stage at the semiconductor manufacturer's facility. In addition to cryogenic liquid delivery, nitrogen gas also is provided through direct pipeline delivery, as well as at customer on-site nitrogen-generation plants.

Specialty Gases. A large number of gases (more than 35) are classified as semiconductor specialty gases. For that reason, a further segmentation of this category is necessary and is based on the chemical reactivity and functionality of the various specialty gases. Dataquest segments the specialty gas market into six categories: silicon-precursor gases, dopants, etchant gases, reactant gases, atmospheric/purge cylinder gases, and others. Specialty gases are used in comparatively smaller volumes than bulk gases; thus, they are delivered in high-pressure cylinders.

Dataquest estimates that the 1989 world market for semiconductor bulk and specialty gases was approximately $705 million.

Semiconductor Gas Suppliers

Several factors will dictate the success of a gas company supplying the semiconductor industry. These include an extensive distribution network, some level of primary manufacturing capability, and a strong service organization.

Five companies and their associated operations dominate the world's semiconductor gas industry today. These major suppliers of semiconductor gases have a good-to-strong presence in the four major semiconductor production regions of the world: Japan, the United States, Europe, and the Pacific Rim. This presence is achieved through overseas operations, equity investment positions in foreign gas companies, or technical/marketing agreements.

For the major gas suppliers, the semiconductor gas market represents only a small portion of a company's total gas business activities. Some of the nonsemiconductor gas applications that represent far larger market opportunities include nitrogen for frozen food processing, oxygen for steel processing, and hydrogen for fuel cells in the rocket and aerospace industries. However, the semiconductor industry represents probably the most rigorous demands on gas suppliers with regard to providing high-purity materials and delivery systems. Therefore, success in the semiconductor gas industry promotes a gas supplier's presence at the cutting edge of gas technology.

Factors that Characterize the Semiconductor Gas Industry

Several unique factors characterize the semiconductor gas market, including the following:

- The specialty gas companies are unique when compared with other electronic materials companies that sell products to the semiconductor industry. What makes this market different is that no one specialty gas company has primary manufacturing capability for all of the specialty gases that it provides to the industry. Thus, a specialty gas company typically must buy some of its products from a competitor.

- Nitrogen is consumed by the semiconductor industry in substantially larger volumes than any other gas and accounts for approximately 80 percent of semiconductor bulk gas sales. While bulk and specialty gas usage typically tracks with semiconductor device production levels and the consumption of silicon wafers, nitrogen also is used to maintain the integrity of processing equipment whether wafers are being processed or not. This means that the nitrogen market, unlike other electronic materials, is very stable even during the times of low production associated with downturns in the semiconductor business cycle.

- The semiconductor bulk gas industry is characterized by long-term contracts between vendor and customer because of the support equipment required at the customer's site for the on-site storage of bulk gases. Typically, one bulk gas supplier supports each fab facility, and that company often will receive the initial gas contract before construction even begins on a new fab. In contrast, the specialty gas industry is characterized by short-term contracts and an ongoing competitive market environment. Multiple specialty gas vendors per fab is the norm rather than the exception.

Background—Semiconductor Equipment

Initially, in the 1950s and 1960s, because there was no commercial source for semiconductor equipment, such equipment was built for internal use by semiconductor producers such as AT&T, IBM, Motorola, and Texas Instruments. In the late 1960s and 1970s, merchant semiconductor equipment manufacturers began to provide equipment to world semiconductor producers. In the beginning, most of the companies were of US origin, with the Japanese and European equipment manufacturers following somewhat later. Major semiconductor companies began to depend on merchant semiconductor equipment suppliers, and equipment that was internally supplied by semiconductor producers began to decline. Thus, the merchant semiconductor equipment industry is approximately 20 years old, and it is interesting to note that several of the world's major equipment manufacturers celebrated their 20-year anniversaries in 1988.

The demand for semiconductor equipment in Japan was fueled by the rise of the Japanese semiconductor industry in the early 1970s, and this demand was met by two sources. The first was the rise of the indigenous Japanese equipment industry, and the second was the transfer of equipment technology to Japan from the United States. US equipment manufacturers, in an effort to penetrate the fast-growing Japanese equipment market, provided Japanese equipment manufacturers access to US-developed technology. By the late 1970s and early 1980s, Japanese equipment companies emerged as merchant suppliers, providing crucial technologies for new VLSI devices manufactured by the fast-growing Japanese semiconductor companies. In 1989, Japanese wafer fab equipment companies shared five of the top ten places in the ranking of worldwide wafer fab equipment suppliers. In terms of world market share for wafer fab equipment, Japanese equipment companies have taken the lead in total market share over US equipment suppliers. In certain equipment categories (for instance, lithography) Japanese equipment makers clearly dominate the world market.

Semiconductor Manufacturing Equipment—Product Overview

The equipment used for the production of semiconductor devices is divided into two major segments: wafer fabrication (front end) equipment and assembly and test (back end) equipment.

Wafer fab equipment is the very sophisticated capital equipment used to manufacture IC devices on the silicon wafer. Front-end, or wafer fab, equipment includes those crucial technologies required for manufacturing critical VLSI devices such as 4Mb and 16Mb DRAMs, 32-bit and larger microprocessors, and advanced logic devices.

IC manufacture, or the wafer fabrication process, takes place in a special ultraclean facility called the fab or clean room. Bare silicon wafers are the input material to the wafer fab; finished silicon wafers are the output of the fab. In many cases, each wafer contains hundreds of manufactured ICs.

The finished wafer then is sent to the assembly and test facility, where the wafer is cut up into individual ICs. The good ICs are separated from the bad; the good ICs are then assembled and packaged and each packaged IC tested. Generally, the wafer fabrication facility and the assembly and test facility are separate; in many cases, the latter facility may be located in another country.

Technical advances in wafer fab equipment directly affect advances in manufacturing ICs. This means that more sophisticated ICs with more functionality or higher speeds or both can be manufactured. As more sophisticated ICs become available, more advanced electronic equipment becomes available, forging a direct link between wafer fab equipment and advanced computers and telecommunications equipment. Thus, technology leadership in the relatively small $5.9 billion worldwide wafer fab equipment market is the gateway to leadership in the $653 billion worldwide electronic equipment market. In addition, the semiconductor company that uses the latest wafer fab equipment will have a competitive advantage in the IC market.

As more sophisticated ICs are manufactured, more sophisticated assembly and test equipment must be developed; in conjunction with the advances in equipment, advances must be made in semiconductor materials as well. However, the driving force in semiconductor manufacturing is wafer fabequipment, or the ability to manufacture the advanced IC itself. This is the area that tends to drive advances in materials as well as in assembly and test equipment. For this reason, the remainder of this chapter will focus on wafer fab equipment. This is not to minimize the strategic importance of semiconductor materials and assembly and test equipment, but rather to recognize that technology leadership in wafer fab equipment is more closely linked with leadership in the huge electronic equipment market.

Of the total amount of capital spending by the world's semiconductor manufacturers, approximately 80 percent is spent on front-end and back-end equipment; of this amount, 60 percent is spent on wafer fab equipment. Thus, wafer fab equipment represents approximately 50 percent of the spending by the world's semiconductor producers and reached almost $6 billion in 1989.

Wafer fabrication equipment is divided into 11 major categories, 8 of which are briefly described in the following paragraphs. This equipment is used to perform the approximately 400 steps required to make an advanced IC. In its simplest description, the IC wafer fabrication process can be divided into three basic operations: thin films are deposited on the silicon wafer, the deposited films are patterned, and the film characteristics are altered.

Lithography

If wafer fab equipment is the driving area for IC production, lithography is the very heart and core of advanced IC manufacturing technology. Lithography is the engine that drives all other technologies used in IC manufacturing. It is the critical patterning technology for VLSI devices because it is the technology enabler for fine-line geometries. The term fine-line geometry refers to the minimum geometries of semiconductor devices. The finer the geometry, the more transistors the IC designer can put on a chip or the more functionality the chip has. For instance, a 1Mb DRAM, which has more than 1 million transistors on the chip, is fabricated with minimum feature sizes of approximately 1.2 micron (the diameter of a human hair is 100.0 microns). Advances in lithography tools now allow 0.8-micron feature sizes to be produced on the chip. With this finer feature size, 4Mb DRAMs containing more than 4 million transistors can be produced. Currently, advanced lithography tools can pattern lines as small as the 0.5-micron feature sizes required for 16Mb DRAMs. Finer geometries also mean that faster chips can be produced, which are essential for building ever-faster computers.

Lithography equipment includes contact and proximity aligners, scanning projection aligners, steppers (reduction and 1:1), e-beam systems, X-ray aligners, and the recently announced step-and-scan aligner, each of which is described briefly as follows:

- Contact/proximity aligners—the industry's first lithography tools, which reach back to the very beginnings of the semiconductor industry—have declined. Today, they are a $20 million niche market. This product is not likely to play a major role in the future lithography market.

- Scanning projection aligners superseded contact/proximity aligners to become the dominant lithography tool for many years. However, this tool is limited in its ability to pattern fine features, and it eventually gave way to steppers.

  - Projection aligners reached their peak in 1984 and 1985 and have since declined to a $94 million market in 1989, representing only 6.5 percent of the total world lithography market of $1,453 million.

  - More than 3,000 of these aligners are in the field, and this base of aligners will continue to grow slowly to provide additional capacity in existing fabs. However, the newer advanced fabs are not being outfitted with scanning projection aligners.

- Steppers, because of their inherent ability to pattern finer features than scanning projection aligners, have become the dominant and state-of-art lithography tool.

  - In 1989, steppers accounted for $1,191 million, or 82 percent, of the total lithography market. Steppers probably will continue to dominate the lithography market for several years.

  - Today, all advanced ICs are fabricated using steppers, and production-worthy steppers in the most advanced fabs can pattern 0.7-micron features. Advanced excimer laser steppers that can pattern 0.35-micron features are under development.

  - Steppers have a solid technology grasp on the lithography market, but it could be weakened by the recent advent of the step-and-scan aligner.

- The potential of the step-and-scan aligner, which was recently introduced to the marketplace, is still uncertain.

  - If successful, step-and-scan systems could compete with steppers and erode their market share.

  - This aligner is a hybrid system that combines the best of both scanning projection technology and stepper technology. It currently appears to be the most advanced aligner on the market, but because it is a new system, field experience is not yet available.

  - This aligner can pattern 0.5-micron features with a wafer throughput that excels steppers, and it is the dark horse in the lithography race.

- E-beam lithography systems have two niche applications.

  - E-beam is the technology used by the worldwide maskmaking industry to produce the masks and reticles required by semiconductor manufacturers for their projection aligners and steppers.

  - E-beam also is used to "direct write" a wafer in special instances, such as quick-turn IC prototyping and small quantity ASIC devices.

  - Together, these two niche markets accounted for $143 million of the 1989 lithography market. However, because of its very low productivity and high cost per wafer, e-beam is not likely to be a mainstream lithography technology, although it can pattern finer geometries than steppers.

- The world semiconductor manufacturers have essentially ignored X-ray aligners (the 1989 market was $5 million) in spite of the numerous advantages of X-ray aligners over conventional optical aligners such as steppers.
  - The semiconductor industry is very slow to accept new technologies, and because the stepper manufacturers continue to make advances in stepper technology, the market window for X-ray aligners continues to be pushed out.
  - Currently, there are X-ray aligners on the market that can pattern 0.5-micron features and less. These aligners are standalone systems and resemble conventional steppers; it is uncertain just how much less than 0.5-micron they can be used in a production environment.
  - However, considerable worldwide development is under way on another type of X-ray technology called synchrotron orbital radiation (SOR) that will have a production limit of approximately 0.2 micron.
    - The Japanese are making very heavy investments in this technology.
    - In addition, IBM already has invested $500 million in SOR and expects to spend $1 billion by the time the system is fully developed.

In summary, steppers are the dominant tool today and will continue to be the dominant tool until the industry reaches 0.5-micron feature sizes, probably by the mid-1990s. At that point there are several competing technologies, and currently it is not clear which technology will be dominant. The dominant technology may very well continue to be steppers, but we must wait for further developments before reaching more secure predictive ground.

Automatic Photoresist Processing Equipment

Automatic photoresist processing equipment, or track equipment as it is commonly known, is used to apply and process the photoresist film that is temporarily applied to the wafer to allow patterning of the wafers by the lithography equipment. The main technical objectives of track systems are to deposit the thin photoresist coatings prior to the patterning process that takes place in the lithography tool and to develop the photoresist after patterning.

Track equipment includes wafer clean/bake, wafer prime, coat/bake, develop/bake, and photoresist stabilization equipment. Track equipment is used in the lithography cell of the wafer fab and actually can be considered part of the lithography process. Because of this, the demand for track systems is closely tied to lithography demand and has about the same compound annual growth rate (CAGR). In 1989, the demand for track equipment reached $325 million.

Etch and Clean

This segment includes wet process, dry etch, dry strip, and ion milling equipment. Wet processing, so-called because ultrapure water and liquid chemicals are used in the process, is used throughout the wafer fab for the cleaning and wet etching of wafers. Wet processing goes back to the early days of the semiconductor industry. Etching, along with lithography and track equipment, is another of the equipment technologies that is part of patterning thin films on the wafer.

Wet etching is used for patterning relatively large features on the wafer, while dry etching, the newer technology, is used almost exclusively in the fabrication of advanced devices that require fine-feature patterning. As advances in lithography equipment allow finer features to be patterned on the wafer, concomitant advances in dry-etch equipment need to be made to fully implement the fine-pattern features on the wafer.

Dry-strip equipment is used to remove the photoresist films that are temporarily applied to the wafer to allow patterning. The total etch-and-clean market was $1,066 million, of which $306 million was for wet-process equipment, $636 million was for dry-etch equipment, and $116 million was for dry-strip equipment.

Deposition

Deposition includes several technologies that are used to deposit thin films on the wafer. The three major technologies included in this category are chemical vapor deposition (CVD), physical vapor deposition (PVD), and epitaxy. Epitaxy technology includes silicon epitaxy, metalorganic CVD, and molecular beam epitaxy equipment. Once these films are deposited by any of three major techniques, they are patterned with the aid of the lithography, track, and etch equipment previously described.

CVD equipment generally is used to deposit insulator films on the wafer, while PVD is used to deposit the aluminum films that are required to wire-up, or connect, all of the transistors on a chip (more than 4 million transistors are used, for example, in the case of 4Mb DRAMs). Collectively, CVD and PVD equipment is used to fabricate the interconnect portion of the chip. As with advances in lithography, advances in CVD and PVD equipment need to be made in order to keep up with current technologies. When new advanced steppers are introduced that have ever-smaller fine-pattern capability, it sets off a new round of development in CVD and PVD equipment (as well as in other front-end equipment); CVD and PVD manufacturers then must struggle to keep pace. For instance, the equipment and technology required to interconnect the more than 4 million transistors of a 4Mb DRAM are vastly more sophisticated (and costly) than was required for the 65,000 transistors of a 64K DRAM of a few years ago. In the past, the portion of chip fabrication cost that was attributed to chip interconnection was small. With advanced chips that have several levels of interconnection on the chip, the cost of interconnection can be 50 percent or more of the entire wafer fabrication cost.

In 1989, the total deposition market was $1,145 million; CVD accounted for $580 million of this market, PVD for $377 million, and total epitaxy for the remaining $189 million. There is currently a tremendous amount of activity in both the CVD and PVD technology areas as new equipment is being introduced to fabricate the most advanced ICs.

In PVD equipment, attention is being directed toward integrated processing systems that will be able to handle several process steps in one piece of equipment instead of having to move the wafer to several pieces of equipment to accomplish the same number of process steps. Generally, as advance chips need to be manufactured, the semiconductor industry will move to more integrated manufacturing. This eliminates human handling of the wafers, decreases contamination, and increases yields.

We said previously that lithography essentially drives the other technologies used in the fabrication of a wafer. Although lithography tools are well on the path to fine-line patterning, work still needs to be done in the deposition of thin films, either by CVD or PVD.

Diffusion Furnaces

Diffusion furnace equipment includes both horizontal and vertical tube furnaces. These high-temperature furnaces are used to incorporate precise quantities of impurities, or dopants, into the deposited films on the wafer in order to control the electrical properties and, hence, the performance of the IC. Other applications include the growing of oxide films, the deposition of insulator films, and annealing.

Horizontal tube furnaces, the workhorses of the industry since their inception, have been losing ground to other technologies such as ion implantation and CVD equipment. For advanced devices, ion implantation now is the preferred method of introducing impurities into the wafer, and CVD is the preferred technology for film deposition. Although the number of horizontal furnaces has declined substantially since the technology's peak a few years ago, ASPs have risen to the extent that horizontal furnace sales reached a record $327 million in 1989.

Vertical furnaces are an emerging technology. Vertical furnaces have several advantages over horizontal furnaces, particularly for advanced devices, and they are being rapidly accepted in Japan. Some advantages include lower power consumption, smaller space requirements, easier automation, and excellent technical performance. In the past, only horizontal furnaces were used in the fab, but Japan expects vertical furnaces to be the dominate furnace technology of the future. In other regions of the world, vertical furnaces have been given a lukewarm reception. Vertical diffusion furnace sales were $90 million in 1989.

Rapid Thermal Processing

Rapid thermal processing (RTP) is a high-temperature technology that was expected to supplant the annealing process of diffusion furnaces. However, this equipment has not found its way into the production mainstream of the wafer fab for this application because anneals done on diffusion furnaces are superior to RTP anneals. RTP is beginning to find opportunities in other applications in the wafer fab, such as in the thin-film area, but these are still emerging. In 1989, the RTP market amounted to $28 million.

Ion Implantation

In the past, introduction of impurities into the thin films on the IC was done in diffusion furnaces, but diffusion furnaces are inadequate for advanced devices that have fine features. Ion implanters provide a much more precise control of the amount, location, and depth of the impurity into the thin film. Implanters are classified as medium current or high current, depending on the amount of impurity that can be incorporated quickly into the film. High-voltage implanters also can incorporate impurities to a greater depth in the film than can either medium- or high-current implanters. It is interesting to note that implanters are essentially linear accelerators and have their roots in that technology. In 1989, the total world market for implanters was $468 million.

Diffusion furnaces, rapid thermal processing equipment, and ion implanters all are used in the wafer fabrication process essentially to modify the thin films that were deposited and patterned by the other equipment technologies described previously.

Critical Dimension/Wafer Inspection

Critical dimension (CD) and wafer inspection equipment are two types of process control equipment. Process control equipment is used to verify the wafer fabrication process rather than contribute to the actual fabrication of the IC. CD equipment is used to measure the features on the wafer to ensure that the patterning process is indeed doing what it is supposed to do. Wafer inspection equipment is used to check for defects on the wafer. Both CD and wafer inspection equipment have a tremendously wide variance in price, depending on the level and sophistication of operator automation. Systems may range from $50,000 for a low-end manual system to $1.2 million for a fully automated advanced system.

CD and wafer inspection equipment technology also is driven by advances in lithography. As finer and finer features are fabricated on the IC, it becomes necessary to measure smaller and smaller features with greater accuracy and precision. Also, as feature sizes get smaller, it becomes necessary to check for ever-smaller defects, and to identify new types of defects. In 1989, the combined markets for CD and wafer inspection equipment totaled $187 million.

Sources of Semiconductor Equipment Demand

The two fundamental sources of demand for semiconductor production equipment are as follows:

- Semiconductor producers purchase advanced equipment to increase competitiveness by decreasing manufacturing cost through advanced manufacturing technology.
- Semiconductor producers purchase equipment to expand production capacity.

Advanced Manufacturing Technology Increases Competitiveness

The primary driving force for new semiconductor equipment for the next two to three years will be the need for advanced manufacturing technology. As mentioned previously and discussed fully in Chapter 6, the success and growth of semiconductor producers within a given region depend ultimately on their relative competitiveness. This competitiveness is determined by regional economic factors such as cost of labor, cost of capital, and availability of patient capital, but it ultimately is reduced to relative product quality and manufacturing costs.

Thus, relative competitiveness depends on the following:

- Efficiency—Higher yields provide lower cost per device.
- Fast turnaround—The earlier a producer gets to market and moves down the learning curve, the more costs become lower and remain lower than those of competitors that enter the market later.
- Higher quality and reliability—The quality and reliability of devices are more important to the device user than the absolute price.

Semiconductor equipment demand based on upgrading competitiveness through manufacturing technology therefore is driven by these factors. Key manufacturing technologies that contribute to these factors are those that contribute to smaller feature sizes, higher productivity, and reduced contamination. Smaller feature sizes provide increased functions per die, higher speeds, and increased die per wafer. Higher productivity translates into more ICs manufactured per time period, and reduced contamination contributes to higher yields, or more good die per manufacturing run.

Another key manufacturing parameter is turnaround, or cycle time, which is the length of time it takes to fabricate a wafer. A producer with shorter cycle times than its competitor moves down the learning curve faster because it is able to correct the IC fabrication process when necessary in a shorter interval of time. As the producer moves down the learning curve, its manufacturing costs decline with a concomitant competitive advantage. Therefore, the key technology demand drivers for manufacturing equipment are all related to the front-end process. Table 7-2 shows the worldwide wafer fab market for 1989 by equipment segment.

Table 7-2

1989 Worldwide Wafer Fab Equipment Demand (Millions of Dollars)

Equipment	Demand
Lithography	
Contact/proximity	20
Projection aligners	94
Steppers	1,191
Direct-write e-beam	70
Maskmaking e-beam/laser	73
X-ray	5
Total Lithography	1,453
Automatic Photoresist Processing Equipment	325
Etch and Clean	
Wet process	306
Dry strip	116
Dry etch	636
Ion milling	9
Total Etch and Clean	1,066
Deposition	
Chemical vapor deposition	580
Physical vapor deposition	377
Silicon epitaxy	72
Metalorganic CVD	44
Molecular beam epitaxy	73
Total Deposition	1,145
Diffusion	327
Rapid Thermal Processing	28
Ion Implantation	468
CD/Wafer Inspection	187
Other Process Control	485
Factory Automation	195
Other Wafer Fab Equipment	206
Total Wafer Fab Equipment	5,887

Note: Columns do not add to totals shown because of rounding.
Source: Dataquest (August 1990)

Capacity Utilization Drives Capacity Expansion

The second driving force behind equipment demand is the requirement to increase production capacity. As regional producers realize success and growth through superior relative competitiveness, they use up existing production capacity and must invest in capacity expansion. Therefore, not only does the semiconductor equipment supplier contribute to the growth and success of the semiconductor producer by improving competitiveness, the producer's success fuels the growth and success of the supplier as well.

Figure 7-2 presents regional capacity utilization by regional company base for North America, Europe, and Japan. Table 7-3 compares historical worldwide merchant semiconductor production with worldwide capital spending and wafer fab equipment demand.

In a time of rapidly expanding demand for semiconductors, the demand for equipment surges. This is illustrated by the boom period of 1983 and 1984, as producers in all regions eagerly expanded capacity in response to the buoyant PC-driven semiconductor demand forecast. This resulted in a capacity utilization and equipment demand peak in 1984. The subsequent collapse of semiconductor demand in the following two years resulted in a severe downturn of equipment demand as capacity utilization plummeted.

The strong recovery of semiconductor demand from 1987 through the present has generated higher demand for production equipment. Table 7-3 shows that the worldwide demand for semiconductor front-end equipment has increased 20 percent in 1989 over 1988. However, as the next paragraphs will show, most of this growth in equipment demand in the 1987 through 1989 period was for competitiveness improvement rather than capacity expansion, because only now are utilization rates beginning to exceed those of the boom years. Table 7-3 also illustrates that 49 percent of the total capital spending by semiconductor manufacturers is spent on wafer fab equipment. Dataquest estimates that the balance of the spending goes to purchase back-end equipment (31 percent) and property and facilities (20 percent).

Table 7-3

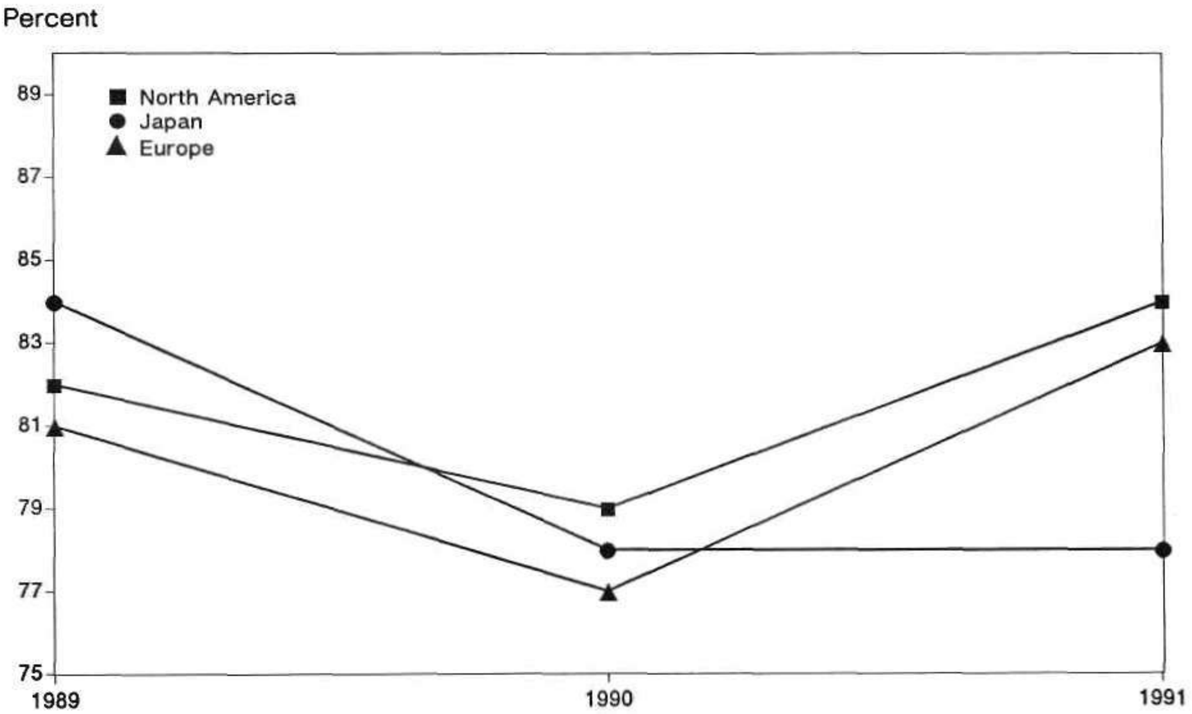
Worldwide Electronic Equipment and Semiconductor Consumption 1988-1989 (Includes Captive Suppliers)

	1988	1989
Electronic Equipment Production	$618.1	$653.1
Semiconductor Production	$ 54.5	$ 59.9
Capital Spending ($B)	$ 10.0	$ 12.2
Capital Spending Annual Growth	56.8%	21.4%
% of Production	18.3%	20.2%
Front-End Equipment Demand ($B)	$ 4.9	$ 5.9
% of Capital Spending	49.0%	48.4%
Annual Growth of Equipment Demand	58.2%	20.3%

Source: Dataquest (August 1990)

Figure 7-2

Estimated Regional Semiconductor Capacity Utilization 1989-1991



Source: Dataquest (August 1990)

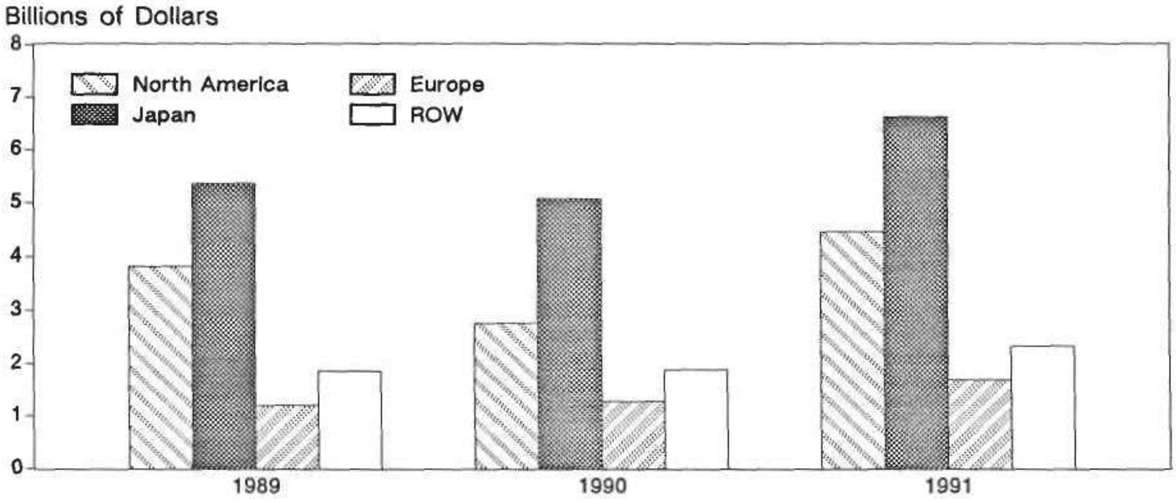
Regional Demand History 1984 to 1989

Figure 7-3 illustrates the regional capital spending of merchant and captive producers regardless of nationality. This represents the regional total available market for goods purchased from such capital expenditure.

Figure 7-4 compares the capital spending in just Japan and North America for the period 1989-1991. In 1984 and 1985, spending in Japan was significantly higher than in North America. However, in 1986 and 1987, capital spending in Japan was slightly less than capital spending in North America. In 1988, the Japanese market for capital equipment underwent a strong comeback

Figure 7-3

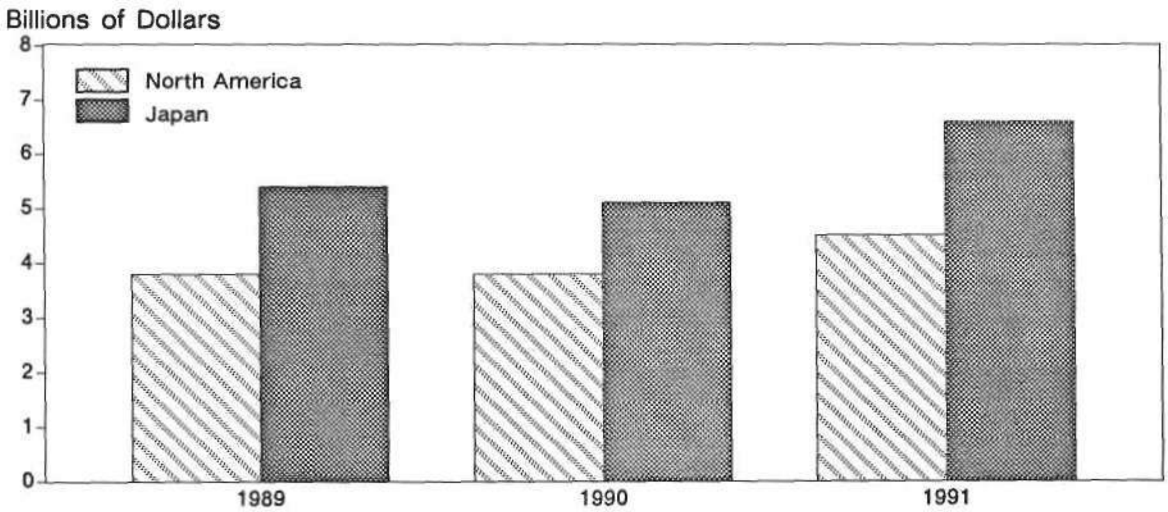
Worldwide Capital Spending Forecast Regardless of Company Regional Base 1989-1991



Source: Dataquest (August 1990)

Figure 7-4

Estimated Regional Semiconductor Capital Spending 1989-1991



Source: Dataquest (August 1990)

and spending in Japan again exceeded that in North America. In 1989, this capital spending gap widened. The capital spending forecast expects capital spending in Japan to continue to exceed capital spending in North America.

Semiconductor Equipment Demand Forecast 1990 to 1991

The equipment demand forecast by segment is shown in Table 7-4. The market reached an all-time high in 1989 with total sales of $5,887 million, which represented a growth of 20.4 percent over 1988. The market is expected to slow down, however, and 1990 sales are projected to be $5,714 million, for a negative growth of approximately 3.0 percent. We expect 1991 sales will be up at $6,832 million. The overall CAGR for the total equipment market is forecast to be 7.7 percent from 1989 to 1991.

Capital spending as a percentage of production is shown in Figure 7-5. Capital spending as a percentage of production exceeded 30 percent in Japan in 1984 and in 1985, compared with 23 and 21 percent for capital spending in North America. However, in 1986 and 1987, the ratio of capital spending to production in Japan fell below the ratio of capital spending to production in North America. In 1988, the ratio of capital spending to production was greater in Japan than in North America; this relationship continued in 1989. The forecast for this ratio is for it to continue to be higher in Japan than in North America.

The largest equipment segment is that of lithography, followed by deposition and etch and clean. Recently, deposition has been the most rapidly growing segment; however, lithography equipment growth is expected to lead the way through 1991. Deposition is forecast to have a 6.7 percent CAGR from 1989 through 1991. Lithography is expected to have only a 10.2 percent CAGR during the same time frame.

The regional capital spending forecast is shown in Table 7-5. Capital spending is forecast to decline by 2 percent in 1990 and grow at a rate of 26 percent in 1991. Most of the predicted decline may be attributed to Japanese producers as their capacity utilization falls off somewhat due to the forecast decline in semiconductor production (see Chapter 6). Dataquest forecasts a healthy increase in demand for semiconductor equipment beyond 1990 as device production is forecast to expand vigorously in all regions.

The regional demand for equipment during the forecast period follows the semiconductor production and capital spending pattern forecast in Chapter 6 (see Table 7-4). We expect the Asia/ROW and European regions to show the most capital spending growth with 1989 to 1991 CAGRs of 12.2 percent and 18.5 percent, respectively. Capital spending for US and Japanese companies is much greater but is forecast to grow more slowly due to the forecast production slowdowns in these two regions. The forecast for capital spending by region of production, regardless of company origin, is shown in Figure 7-6.

In terms of dollars, the spending levels within Japan by Japanese and American producers will exceed spending levels in North America by substantial margins. In 1990, our forecast calls for capital spending in Japan to be 135 percent of capital spending in North America. By 1991, spending in Japan will be 149 percent of capital spending in Europe.

Strategic Issues Regarding the Equipment Demand Forecast

Impact of Regional Economy on the Forecast

The regional economic forecasts were provided in Chapter 3 and related to semiconductor production in Chapter 6. The fundamental economic impact on equipment demand is that which modulates semiconductor production and therefore demand for equipment that upgrades competitiveness or expands capacity. The relaxation of economic growth forecast worldwide, particularly in the United States, probably will moderate demand and production of semiconductors in 1990, especially in Japan, causing a predicted negative demand growth for equipment that year.

Table 7-4

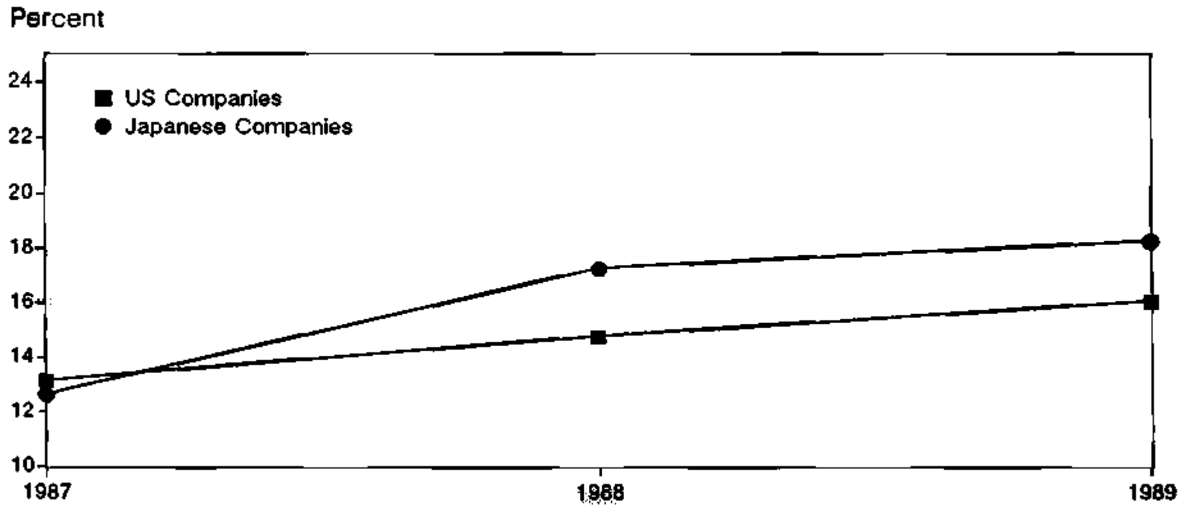
Worldwide Wafer Fab Equipment
Forecast
(Millions of Dollars)

	1989	1990	1991	CAGR 1989-1991
Lithography				
Contact/proximity	20	20	22	4.9%
Projection aligners	94	90	122	13.9%
Steppers	1,191	1,225	1,450	10.3%
Direct-write e-beam	70	72	80	6.9%
Maskmaking e-beam/laser	73	74	86	8.5%
X-ray	5	4	6	9.5%
Total Lithography	1,453	1,485	1,766	10.2%
Automatic Photoresist Processing Equipment	325	330	390	9.5%
Etch and Clean				
Wet process	306	293	350	6.9%
Dry strip	116	110	130	5.9%
Dry etch	636	620	732	7.3%
Ion milling	9	10	12	15.5%
Total Etch and Clean	1,066	1,033	1,224	7.2%
Deposition				
Chemical vapor deposition	580	560	675	7.2%
Physical vapor deposition	377	360	432	7.0%
Silicon epitaxy	72	46	61	(8.0%)
Metalorganic CVD	44	45	50	6.6%
Molecular beam epitaxy	73	75	85	7.9%
Total Deposition	1,145	1,086	1,303	6.7%
Diffusion	327	300	375	7.1%
Rapid Thermal Processing	28	26	34	10.2%
Ion Implantation	468	417	509	4.3%
CD/Wafer Inspection	187	195	238	12.8%
Other Process Control	485	470	553	6.8%
Factory Automation	195	170	204	2.3%
Other Wafer Fab Equipment	206	202	236	7.0%
Total Wafer Fab Equipment	5,887	5,714	6,832	7.7%

Note: Columns may not add to totals shown because of rounding
Source: Dataquest (August 1990)

Figure 7-5

Semiconductor Capital Spending as a Percent of Semiconductor Sales



Source: Dataquest (August 1990)

Table 7-5

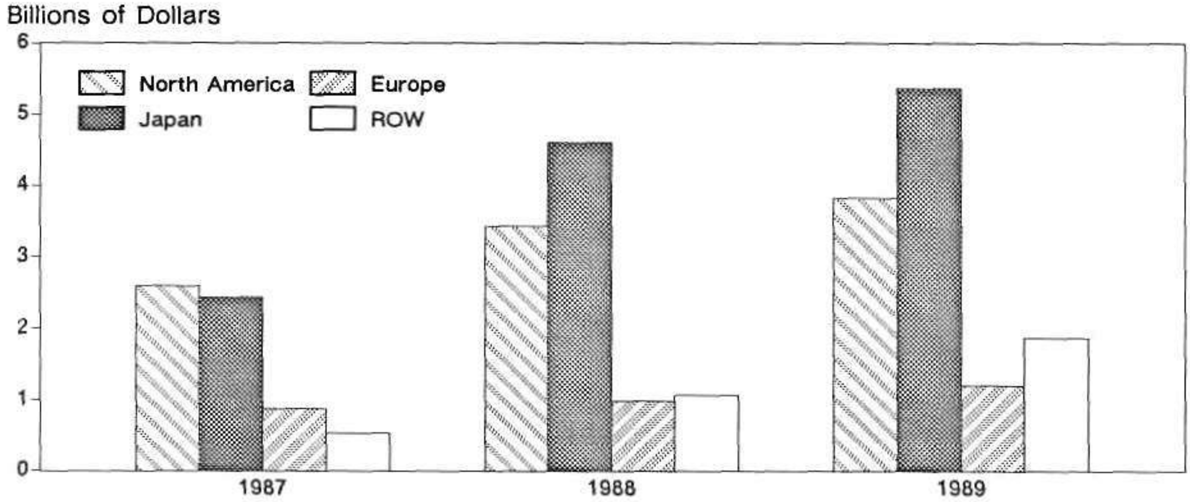
Regional Capital Spending
1989-1991
(Includes Captive Production Capital Spending)

	1989	1990	1991	Share 1989	Share 1991	CAGR 1988-1990
Worldwide Capital Spending						
US	3,822	3,759	4,465	31.2%	29.5%	8.1%
Japanese	5,368	5,089	6,635	43.8	43.9	11.1%
European	1,201	1,273	1,686	9.8	11.2	18.5%
ROW	1,854	1,877	2,333	15.2	15.4	12.2%
Total Worldwide Spending	12,245	11,998	15,119	100.0%	100.0%	11.1%
Annual Growth Rate	21.4%	(2.0%)	26.0%			

Source: Dataquest (August 1990)

Figure 7-6

Worldwide Capital Spending by Region
Regardless of Regional Company Base
1987-1989



Source: Dataquest (August 1990)

What Are the Demand Drivers for Semiconductor Production Equipment?

Analysis of new fab capacity from Dataquest's fab database reveals that almost 90 percent of the new fab capacity in 1992 will be submicron.

The majority of equipment demand is forecast to be for upgrading manufacturing technology, which equates to fine-line geometries (sub-1.5-micron), particularly the 0.7- to 0.5-micron, 200mm wafer fab capability required for 1Mb DRAMs and beyond. Therefore, equipment segments that contribute to such fab capabilities will be in higher demand.

Regional Demand/Production Imbalances

The major suppliers of semiconductor production equipment are identified in Table 7-6. As discussed in the previous paragraphs, the regional base of these suppliers has shifted substantially over the period from 1980 to 1990. In 1989, the Japanese took the lead in worldwide market share for all wafer fab equipment for the first time in history, capturing 46 percent of the market compared with the United States' 40 percent. However, the situation is worse for US suppliers than it appears for two reasons. First, the Japanese are becoming increasingly dominant in their own market for equipment. Their share of the 1989 Japanese market for wafer fab equipment was 74 percent, up

Table 7-6

1989 Top 10 Wafer Fab Equipment Suppliers
(Millions of Dollars)

Rank	Company	Revenue
1	Nikon	681
2	Applied Materials	438
3	Tokyo Electron, Ltd.	293
4	Canon	252
5	General Signal	186
6	Hitachi	165
7	Varian	165
8	ASM Lithography	141
9	Anelva	140
10	Silicon Valley Group	127

Source: Dataquest (August 1990)

from 67 percent in 1982. Correspondingly, the US share of the Japanese market in 1989 was 16.2 percent, down from more than 30 percent in 1982. Joint venture companies held 7.9 percent of the market. Second, in the technically critical lithography segment of advanced stepper equipment, Japanese suppliers achieved 76.6 percent of the worldwide market while the US suppliers' share fell to 12.4 percent. This is a technology that was innovated in the United States and at one point was wholly owned by US companies. This also is a technology that is critical to submicron device geometries.

The concentration of market share among the top companies that supply the semiconductor equipment demand is shown in Table 7-7. The top 10 companies hold more than 52.0 percent of the market, and the top 20 control more than 71.0 percent. Furthermore, Table 7-8 illustrates the relative sizes of the wafer fab equipment suppliers. The top 15 companies (11.6 percent of all suppliers) are the only suppliers with revenue in excess of $100 million. The 82.2 percent of the companies, which total 106, have revenue below $50 million. In fact, less than 25.0 percent of the companies account for more than 80.0 percent of wafer fab equipment sales.

Many of these small companies are in niche markets and have opportunities for success and growth. However, the large companies have a firm lock on the bulk of the market. Three of the top five companies are Japanese.

Table 7-7

Worldwide Revenue of Ranked Companies in Key Equipment Areas
(Millions of Dollars)

Companies by Rank	1989 Revenue ($M)	Percentage of Subtotal Fab Equipment
1-10	$2,587	52.1%
11-20	974	19.6
21-30	505	10.2
31-129	904	18.2
Subtotal Wafer Fab Equipment	$4,970	100.0%
Total Market	$5,887	

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1990)

Table 7-8

1988 Revenue Breakdown of Wafer Fab Equipment Companies
(Millions of Dollars)

	Number of Companies	Percent of Companies	Cumulative Percent
0 to $5	39	30.2%	30.2%
$5 to $10	22	17.1	47.3%
$10 to $25	34	26.4	73.6%
$25 to $50	11	8.5	82.2%
$50 to $100	8	6.2	88.4%
$100 to $200	11	8.5	96.9%
$200+	4	3.1	100.0%
	129	100.0%	

Note: Columns may not add to totals shown because of rounding
Source: Dataquest (August 1990)

Access to Capital

Concern exists that the ability for small companies to access sufficient investment capital through the US financial community is so limited that the most successful and strategically positioned companies become targets for acquisition by larger Japanese or European companies. Such acquisitions set up situations where innovative and creative entrepreneurs build a company around key new technologies only to stall out through failure of the financial community to respond appropriately to the strategic significance of the venture.

This situation allows foreign investors with more strategic vision and more patient capital to "cherry-pick" keystone technologies for themselves with little of the entrepreneurial risk. By this means, the independent, free-enterprise system of the United States could become a low-cost "breeding ground" for critical manufacturing technologies with which the Japanese maintain their superior competitiveness.

Continuation of these conditions all but guarantees further erosion of key new semiconductor manufacturing technologies to Japanese equipment suppliers, adding to the staggering regional imbalances that already exist. In the long term, such conditions gradually will eliminate the independent semiconductor producer within the United States. Except for a few specialty areas such as 32-bit microprocessors and the recent SEMATECH effort where the United States has recognized the problem and protected its long-term interests, this loss of domestic semiconductor suppliers would, over time, eliminate the United States as the dominant force in computers, communications, and industrial electronic equipment.

CHAPTER 8

Executive Summary and Conclusions

This chapter presents a summary of the key points from the preceding chapters.

Overview

- In 1989, worldwide merchant semiconductor industry revenue totaled $57.2 billion. This represents a modest 12 percent growth over 1988 and a more than doubling of annual revenue in just four years since the 1985 recession.
- The semiconductor industry is part of the electronics industry, the infrastructure, which is made up of a complex chain of buyers and sellers working together to satisfy worldwide demand for electronic products. This chain consists of several tiers beginning with the demand for electronic equipment, continuing to semiconductor devices, and ending with the demand for semiconductor equipment and materials. Demand for various products flows through the buyer/seller chain from one level to the next, producing a cascading "waterfall of demand."
- Success of the $653.1 billion electronic equipment industry and the $57.2 billion semiconductor industry is dependent on the $18.0 billion semiconductor equipment industry.

Key Economic Points

- Electronic equipment represents nearly 7 percent of the OECD members' output of goods and services. This amounts to $653 billion out of $10 trillion, measured in US dollars.
- Of the three economic sectors—private business, government, and consumer—demand for semiconductor devices is most influenced by private business. Within private business, semiconductor demand is influenced most by capital spending.
- Since 1987, the global economy has been expanding vigorously due primarily to capital spending by businesses.
- Worldwide economic growth is forecast to slow over the next two years.

Semiconductor Demand Summary

- The following three electronic equipment segments are the major contributors to semiconductor growth:
  - Data processing
  - Consumer equipment
  - Communications
- Major growth products have been personal computers, workstations, storage peripherals terminals, personal printers, VCRs, and compact disc players.
- As Japanese and Asian economies surge, they are consuming larger percentages of worldwide electronic equipment; in 1989, they equaled the European economy in size.
- Electronic equipment growth products have the following common attributes:
  - High semiconductor content
  - High unit volume
  - Large market (all of these products are utilized by individuals and thus are ensured of a large total available market)
- Semiconductor demand is dependent on the following:
  - Equipment production growth worldwide
  - Semiconductor pervasiveness has grown from 7.3 percent in 1986 to 9.3 percent in 1989. Semiconductor pervasiveness is measured as the dollar content of semiconductors as a percentage of the dollar value of the finished equipment.

- North America still is the dominant producer of data processing, communications, and industrial electronic products, but a clear trend has emerged that indicates significant erosion in market share for North American suppliers.

- After a decline in the first quarter of the year, worldwide semiconductor demand is forecast to grow through the second half of 1990 as the demand for electronic equipment increases. Worldwide merchant semiconductor demand growth for 1990 is forecast to be a negative 0.7 percent before growing 17.0 percent in 1991. The merchant market is expected to reach $58.2 billion in 1989 and decline to $57.9 billion in 1990.

Semiconductor Production Summary

- With more than 200 companies throughout the world producing semiconductor devices, the Japanese have four out of the top five companies. The top five semiconductor producers are NEC, Toshiba, Hitachi, Motorola, and Fujitsu, in that order.

- Japanese and Asia/Pacific countries have become the dominant forces in the semiconductor industry.

- The demand for semiconductors has shifted dramatically over the last four years as indicated in the following sentences:

  - In 1984, the Japanese and Asia/ROW regions represented $11 billion or only 38 percent of the $29 billion total, while North America's share was $13 billion, or 45 percent.

  - As the North American share of electronic production declined, the semiconductor demand market share fell from 45.0 percent in 1984 to 34.9 percent in 1989.

- Semiconductor product opportunities for the next few years are in the following areas:

  - ASICs
  - Specialty memories—FERRAMs
  - Intelligent power systems
  - Microcomponents

- MOS memory revenue has become a significant factor in measuring the health of the industry. The price of DRAMs can inflate or deflate the overall industry sales volume, causing a distorted view of growth or decline.

- DRAM business is forecast to decline by 32 percent in 1990 and increase by 28 percent in 1991. This DRAM decline will contribute to a slowdown in the overall semiconductor industry in 1990.

- In 1989, MOS memory revenue composed 29 percent of the total merchant semiconductor revenue of $57.2 billion.

- Japanese and Korean producers have 73 percent of the merchant MOS memory market.

- MOS memory and microcomponents were the growth areas in 1989.

- The standalone semiconductor industry as it exists in the United States is threatened by the integrated industry as it exists in Japan. The critical question for US merchant suppliers is: Can US suppliers remain independent and survive?

- Another key question regarding the future of the US semiconductor industry is: Can US suppliers obtain the necessary funds to keep up with Japanese investments?

Semiconductor Equipment and Materials Summary

- We expect semiconductor equipment demand in 1989 and 1990 to be driven by the need for new technology as fab lines come on-line with line geometries of less than 1.5 micron.

- Of all semiconductor materials, only two, silicon and photoresist, have strategic significance.

- Demand for semiconductor equipment is driven by the following:

  - Additional capacity—Producers need to expand capacity.

  - New technology—Producers need to increase competitiveness through new manufacturing technology.

- Manufacturing technology focus is on fab lines that have less than 1.5-micron geometries.
- By 1992, almost 60 percent of the square inches of silicon consumed will have line geometries of less than 1.5 micron.
- The key technology demand drivers for manufacturing equipment is in the front-end (wafer fab) process-related equipment that will do the following:
  - Produce fine-line geometries and provide more functions per die
  - Process larger wafers and yield more die per wafer
  - Minimize contamination and improve yields (track systems)
- X-ray lithography may well be the next critical technology in the pursuit of submicron geometries. Japan recognizes this and is making significant investments.
- Capital spending within semiconductor producers is forecast to grow at an annual rate of 11.6 percent in 1989 and decline slightly in 1990, followed by a healthy demand beyond 1990 as device production expands in all regions. The bulk of the decline in 1989 is forecast to be from Japanese producers as their capacity utilization falls off.
- The top ten companies (10 percent of all suppliers) are the only suppliers with revenue in excess of $100 million. Sixty companies have annual revenue below $50 million.
- Adequate capital is not available within the United States to fund new semiconductor equipment technologies, which leaves an opening for foreign investors to cherry-pick the best technologies. This will cause further elimination of US-based independent suppliers and further weakening of the US semiconductor industry.

United States—Summary Statements

- The US electronics and semiconductor industries are facing critical problems, described as follows:
  - First, the US market for semiconductors is shrinking as a percentage of the worldwide market because of the erosion of market share by US electronics companies.
  - Second, Japanese and Asian semiconductor companies continue to gain share within the United States, while US semiconductor producers are not gaining share in Japan or other Asian countries.
- The three primary causes for the dramatic shift in the balance of economic power between the United States and Japan are shown as follows:
  - Many North American equipment producers moved offshore.
  - A shakeout of US suppliers occurred.
  - The change in the exchange rate caused by the devaluation of the dollar beginning in 1986 caused an inflated view of the Japanese market share.
- The United States now is at risk of becoming a minor player in worldwide electronics market during the last decade of the century.
- Because nearly one-half of the world GNP is contributed by the United States, the continued health of the world economy depends on the health of the United States.
- The US economy is projected to have slower growth beginning in late 1990 and lasting through 1991.

APPENDIX A

Directory of Semiconductor Suppliers

ACC Microelectronics
3333 Bowers Avenue, Suite 215
Santa Clara, CA 95054
408/980-0622

Actel Corporation
955 E. Arquez Avenue
Sunnyvale, CA 94086
408/839-1010

Acumos, Inc.
1531 Industrial Road
San Carlos, CA 94070
415/591-1488

Adaptec, Inc.
691 S. Milpitas Boulevard
Milpitas, CA 95035
408/945-8600

Advanced Hardware Architectures
P.O. Box 9669
Moscow, ID 84843
208/883-8000

Advanced Linear Devices, Inc.
1180 F. Mariloma Way
Sunnyvale, CA 94086
408/720-8737

Advanced Micro Devices, Inc.
901 Thompson Place
P.O. Box 3453
Sunnyvale, CA 94088
408/732-2400

Advanced Microelectronic Products, Inc.
North American Headquarters
1887 O'Toole Avenue, Suite C-111
San Jose, CA 95131
408/727-8880

Advanced Power Technology, Inc.
405 S.W. Columbia Street
Bend, OR 97702
503/382-8082

Altera Corporation
2610 Orchard Parkway
San Jose, CA 95134-2020
408/984-2800

ANADIGICS, Inc.
35 Technology Drive
Box 4915
Warren, NJ 07060
201/668-5000

Applied Micro Circuits Corporation
6195 Lusk Boulevard
San Diego, CA 92121
619/450-9333

Analog Devices, Incorporated
One Technology Way
P.O. Box 9106
Norwood, MA 02062-9106
617/461-3612

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Imperial Tower 1-1
Uchisaiwai-cho 1-chome
Chiyoda-ku, Tokyo, JP

ASEA AB Head Office
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Sweden
46 21 10 00 00

ASEA Brown Boveri
Box 520, S-175 26
Jarfalla, Sweden
010 46 758 24500

Aspen Semiconductors
58 Daggett Drive
San Jose, CA 95134
408/432-7050

AT&T Microelectronics
555 Union Boulevard
Allentown, PA 18103-9989
1-800-372-2447

Atmel Corporation
2125 O'Nel Drive
San Jose, CA 95131
408/441-0311

Austek Microsystems Pty. Ltd.
Technology Park, Adelaide
South Australia 5095, Australia
8/260-0155

Austria MikroSysteme International
Schloss Permstatten
8141 Unterpremastatten
Austria
010 43 31363666271

Bipolar Integrated Technology
1050 Northwest Compton Drive
Beaverton, OR 97006
503/629-5490

BKC International Electronics
6 Lake Street
P.O. Box 1436
Lawrence, MA 01841
508/681-0392

Brooktree Corporation
9950 Barnes Canyon Road
San Diego, CA 92121
619/452-7580

Burr-Brown Corporation
6730 South Tucson Boulevard
Tucson, AZ 85706
602/746-1111

California Micro Devices Corporation
215 Topaz Street
Milpitas, CA 95035-5430
408/263-3214

Calmos Systems, Inc.
20 Edgewater Street
Kanata, Ontario, Canada, K2L 1V8

Calogic Corporation
237 Whitney Place
Fremont, CA 94539
415/656-2900

Catalyst Semiconductor, Inc.
2231 Calle De Luna
Santa Clara, CA 95054
408/748-7700

Celeritek, Inc.
617 River Oaks Parkway
San Jose, CA 95134
408/433-0335

Chartered Semiconductor Pte. Ltd.
3-lim Teck Kim Road
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Singapore 0208

Cherry Semiconductor Corporation
2000 South County Trail
East Greenwich, RI 02818
401/885-3600

Chips & Technologies, Inc.
3050 Zanker Road
San Jose, CA 95134
408/434-0600

Cirrus Logic, Inc.
1463 Centre Pointe Dr.
Milpitas, CA 95035
408/945-8300

Comlinear Corporation
4800 Wheaton Drive
Fort Collins, CO 80525
303/226-0500

Cree Research Inc.
2810 Meridian Parkway
Durham, NC 27713
919/361-5709

Crystal Semiconductor Corporation
4210 South Industrial Road
P.O. Box 17847
Austin, TX 78760
512/445-7222

Custom Arrays Corporation
525 Del Rey Avenue
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408/749-1166

Cypress Semiconductor Corporation
3901 North First Street
San Jose, Ca 95134-1599
408/943-2600

Daewoo Telecommunications Co., Ltd.
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Chung-gu, Seoul, Korea
02-771-35

Dallas Semiconductor Corporation
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The DSP Group, Inc.
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Elantec, Inc.
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Chu Tung, Hsin Chu
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EXEL Microelectronics Inc.
2150 Commerce Drive
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03-216-3211

Gazelle Microcircuits, Inc.
2300 Owen Street
Santa Clara, CA 95054
408/982-0900

General Electric Company
3135 Easton Turnpike
Fairfield, CT 06531
518/438-6500

GE Solid State
Route 202
Somerville, NJ 08876
201/685-6426

General Instrument Corporation
767 Fifth Avenue
New York, NY 10153
212/207-6200

General Instrument
Power Semiconductor Division
600 West John Street
Hicksville, NY 11802
516/933-3000

GigaBit Logic, Inc.
1908 Oak Terrace Lane
Newbury Park, CA 91320
805/499-0610

Goldstar Semiconductor, Ltd.
20, Yoido-dong,
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3800 Homestead Road
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GTE Corporation
One Stamford Forum
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GTE Microcircuits
2000 W. 14th Street
Tempe, AZ 85281
602/921-6526

Harris Corporation
1025 W. NASA Boulevard
Melbourne, FL 32919
407/727-9100

Harris Semiconductor Sector
1301 Woody Burke Road
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Headland Technologies, Inc.
46335 Landing Parkway
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Hecht-Nielson Neurocomputer Corporation
5501 Oberlin Dr.
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Hewlett-Packard Company
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Palo Alto, CA 94304
415/857-1501

Hitachi, Ltd.
6, Kanda-Surugadai 4-chome,
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Holt Integrated Circuits, Inc.
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Integrated Information Technology, Inc.
2540 Mission Boulevard
Santa Clara, CA 95054
408/727-1885

Intel Corporation
3065 Bowers Avenue
Santa Clara, CA 95052-8131
408/987-8080

Intergraph Advanced Processor Division
2400 Geng Road
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El Segundo, CA 90245
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New York, NY 10022
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IXYS Corporation
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916/985-3670

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LSI Logic Corporation
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Lincoln Industrial Park
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06-908-1121

Matsushita Electronics Corporation
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Micro Linear Corporation
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Micro Power Systems, Incorporated
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Microchip Technology Inc.
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Chandler, AZ 85224-6199
602/963-7373

Micron Technology, Inc.
2805 East Columbia Road
Boise, ID 83706
208/283-4000

Microwave Technology, Inc.
4268 Solar Way
Fremont, CA 94538
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Mietec N.V.
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Belgium
055-33-2211

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Kanata, Ontario
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Mitel Semiconductor
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Kanata, Ontario
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Mitsubishi Electric Corporation
Mitsubishi Denki Bldg., 2-3, Marunouchi 2-chome
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Mitsubishi Electric Corporation Semiconductor
Kita-Itami Works
4-1, Mizuhara Itami-City
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6640727-82-5131

Modular Semiconductor, Inc.
138 Kifer Court
Sunnyvale, CA 94086
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MOSel
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Semiconductor Products
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Multichip Technology
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National Semiconductor Corporation
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Santa Clara, CA 95052-8090
408/721-5000

nCHIP, Inc.
1971 North Capitol Avenue
San Jose, CA 95132
408/945-9991

NCR Corporation
Corporate Headquarters
1700 South Patterson Boulevard
Dayton, OH 45479
513/445-5000

NEC Corporation
33-1, Shiba 5-chome
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NEC
Tamagawa Works
1753 Shimonumabe
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New Japan Radio Co., Ltd.
Mitsuya Toranomon Bldg.
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Japan
(03) 502-2331

NMB Semiconductor Co., Ltd.
1580 Yamamoto
Tateyama-shi
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Japan
0470-23-3121

NMB Semiconductor Corporation
9730 Independence Avenue
Chatsworth, CA 91311
818/341-3355

NSI Logic, Inc.
259 Cedar Hill Road
Marlboro, MA 01752
508/430-0717

NovaSensor
1055 Mission Court
Fremont, CA 94539
415/490-9100

Oak Technology, Inc.
139 Kifer Court
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Oki Electric Industry Company, Ltd.
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Pacific Monolithics, Inc.
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Paradigm Technology
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N.V. Philips BV
Components Divison, Building BA
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Semiconductor Industry Insights:
Silicon to Systems

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A Strategic Analysis Report

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A Strategic Analysis Report

Published by Dataquest Incorporated

The content of this report represents our interpretation and analysis of information generally available to the public or released by knowledgeable individuals in the subject industry, but is not guaranteed as to accuracy or completeness. It does not contain material provided to us in confidence by our clients.

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Preface

The semiconductor industry, in the strictest definition, comprises companies that produce semiconductor devices for sale in the open market or for internal consumption. A report on the companies that produce the semiconductors would give a picture of the industry, but not the complete picture. The complete picture emerges when the semiconductor industry is analyzed in the context of the overall structure in which it exists. And that is an interrelated structure that relies on customers, depends on suppliers, and is subject to external pressures from governments and worldwide economic conditions.

With this interrelated industry structure in mind, *Semiconductor Industry Insights—Silicon to Systems* integrates data and concepts from several Dataquest semiconductor services with regional economic forecasts from OECD, D&B, and the US DOC. Written in executive summary style, it is intended to provide high-level, insightful analysis of the recent history and near-term future of the semiconductor industry for semiconductor users, semiconductor producers, suppliers to the semiconductor industry, investors within the industry, and interested parties who want to understand the near-term future of this industry.

Semiconductor Industry Insights—Silicon to Systems was completed in July 1990, and the forecasts and projections contained within this report are based on information from several sources published in late 1989 through July 1990, as follows:

- Source
  - *Economic Outlook* (OECD), published December 1989
  - *US Economic Forecast* (D&B), published April 1990
  - *US Economic Outlook* (DOC), published January 1990
  - *Dataquest Electronic Equipment Forecast*, published May 1990
  - *Dataquest Semiconductor Demand Forecast*, published June 1990
  - *Dataquest Semiconductor Production Forecast*, published June 1990
  - *Dataquest Semiconductor Equipment Forecast*, published June 1990

About Dataquest

Dataquest is a worldwide market research company, headquartered in San Jose, California (Silicon Valley). Dataquest employs more than 700 people worldwide and operates market research resources in Japan and other Pacific Rim locations, Europe, and the United States. As a subsidiary of The Dun & Bradstreet Corporation (D&B), Dataquest has access to major economic forecasting and business databases. In addition, through its own worldwide research resources, Dataquest has compiled the most comprehensive integrated database in the world covering the semiconductor industry and its suppliers and customers.

Dataquest's Database

The Dataquest database is created by research involving ongoing conversations with some 250 different companies worldwide, surveys, examination of public business disclosures such as annual reports from more than 200 other companies, and data made available by D&B.

This database provides the underlying data and is the basis for trend analysis and forecasting at an extraordinarily detailed level for all companies within the electronics industry. Dataquest provides 11 different client services in which the data, analysis, and forecasts are presented in detailed reports, newsletters, and on-line terminal access to the data. These 11 client services are aimed at the particular needs of specific participants within the electronics industry; these services and their relation to the infrastructure are illustrated in the chart that follows.

Semiconductor Industry Insights—Silicon to Systems draws from many of the Dataquest semiconductor industry services as well as other resources available to Dataquest and presents a high-level picture of the semiconductor industry for the 1989 and 1990 time frame. More detailed information on individual subjects is available from Dataquest through subscriptions to the appropriate service.

Figure i

Dataquest's Semiconductor Industry Services

Services	SUIS Semiconductor User Information Service	ASETS Asian Semiconductor and Electronics Technology Service JSIS Japanese Semiconductor Industry Service ESIS European Semiconductor Industry Service SIS Semiconductor Industry Service JSAM Japanese Semiconductor Application Markets ESAM European Semiconductor Application Markets NASM North American Semiconductor Markets SAM Semiconductor Application Markets MilAero MilAero Technology Service	SEMS Semiconductor Equipment and Materials Service
Audience	Semiconductor Buyers	Semiconductor Producers	Semiconductor Equipment and Materials Producers

Source: Dataquest (August 1990)

CHAPTER 1

Introduction

With the first-half results of 1990, the semiconductor industry appears to be emerging from an industry-wide recession that began in the third quarter of 1989. In 1989, worldwide semiconductor industry revenue was $57.2 billion. This amount represents a modest 12 percent growth over 1988 and a more than doubling of annual revenue in just four years since the 1985 recession.

Continued strength of the semiconductor industry in 1990, 1991, and beyond will depend on many worldwide factors, which include the following:

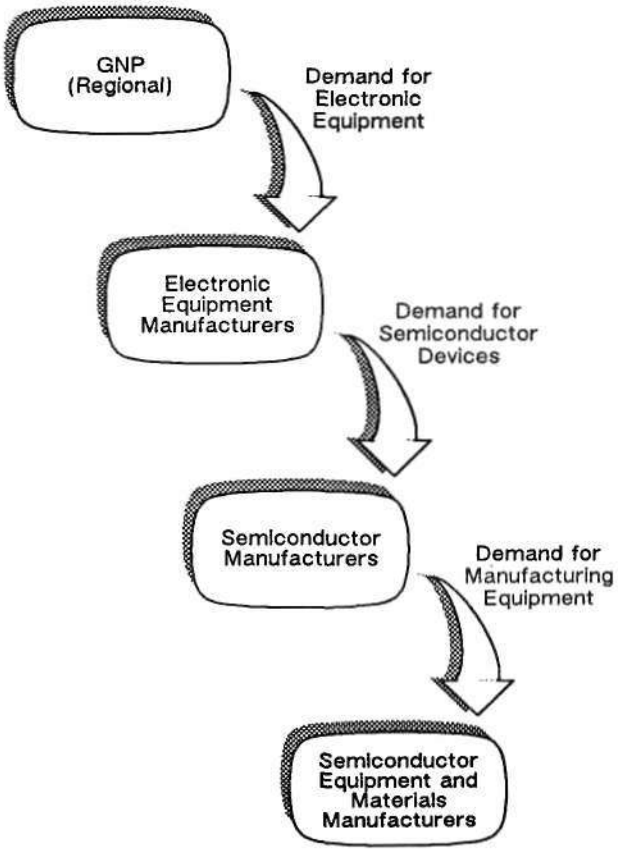
- The continued growth of the economies of the United States and its major trading partners
- The resulting capital spending—with its high content of electronic equipment—in the major industrialized regions of the world
- The continuing demand for semiconductors from producers of electronic equipment within each major industrialized region of the world
- The evolution of semiconductor manufacturing technology
- A continuing flow of new semiconductor products that enable innovative electronic products to stimulate the economies of all regions

Semiconductor Industry Insights—Silicon to Systems provides information and insights about how these factors combine to form and influence the industry infrastructure. These worldwide factors extend beyond the boundaries of companies, governments, and geographic regions. Implicit in these factors is a complex buyer-seller chain in which buyers create demand that pulls products through the chain. This complex chain consists of several tiers, beginning with the demand for electronic equipment, continuing to semiconductor devices, and ending with the demand for semiconductor equipment and materials. Demand for various products flows through the buyer/seller chain from one level to the next, producing a cascading "waterfall of demand," as shown in Figure 1-1.

This waterfall of demand is so fundamental to understanding the industry and the material presented that we have organized this report to follow the waterfall.

Figure 1-1

Waterfall of Demand



Source: Dataquest (August 1990)

Organization of this Report

Information, analysis, and insight are presented within each level of the waterfall so that the reader can understand the infrastructure as it relates to him or her. The issues and economic influences are quite different depending on the level within the waterfall where one sits. The perspective also is different based on whether one has an investor's, banker's, buyer's, or seller's point of view. Figure 1-2 illustrates the different perspectives within the electronics industry infrastructure. Interest in various sections of the report and levels of the waterfall will depend on the reader's individual perspective.

Additionally, investors, bankers, and other interested parties may be interested in all perspectives of the industry.

Chapters Follow the Waterfall

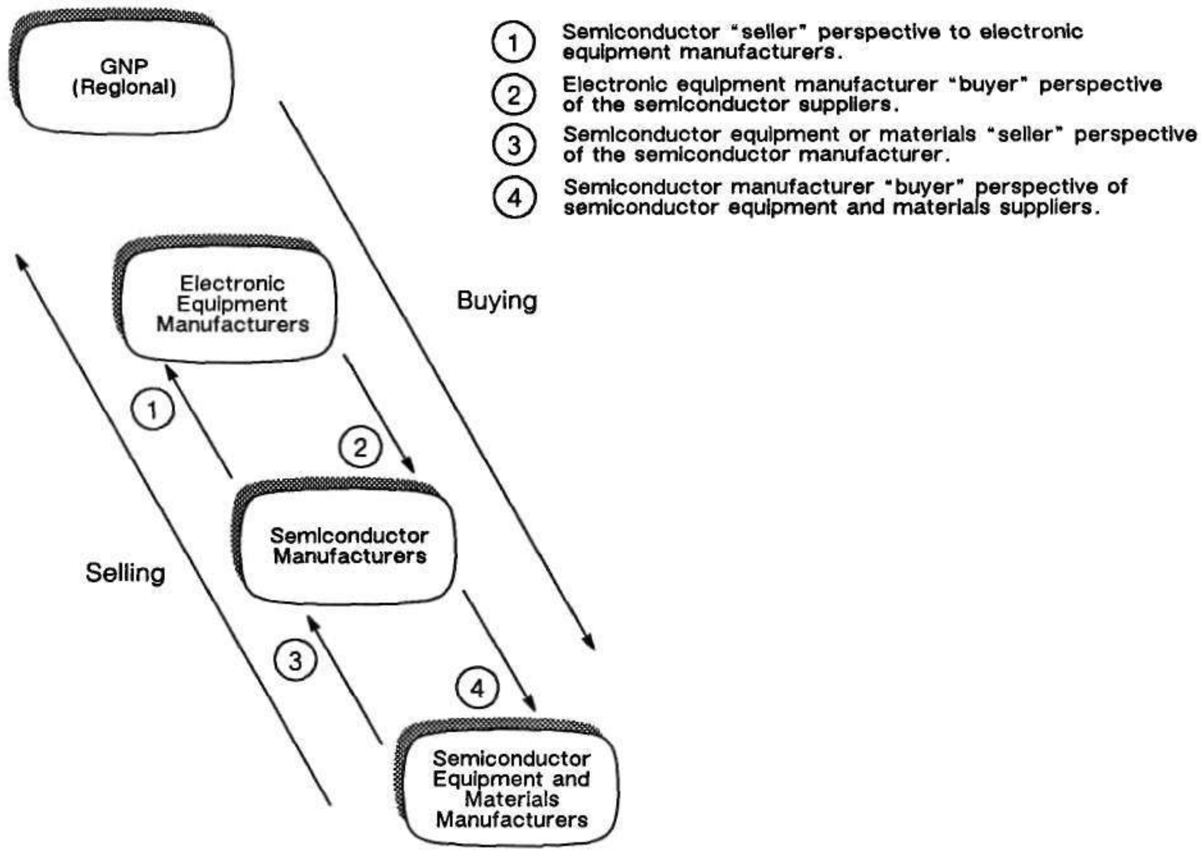
As stated earlier, the purpose of this report is to provide the reader with high-level, insightful analysis of the recent history and near-term future of the semiconductor industry.

Chapter 1 establishes the various reader perspectives and defines terminology.

Chapter 2 provides critical background information leading to 1989 semiconductor industry conditions and describes the industry infrastructure in terms of the demand waterfall.

Figure 1-2

Reader Perspectives



Source: Dataquest (August 1990)

Chapter 3 provides a review of the issues and trends that shaped the semiconductor industry in 1989 and a brief forecast of the worldwide and regional economic conditions. The individual regional economic conditions form the "headwaters" of the waterfall of demand and thus establish the demand and production levels of electronic equipment within each region.

Chapter 4 develops the relationship between regional economic factors and electronic equipment demand and production. The chapter ends with the worldwide forecast of semiconductor purchases by electronic equipment manufacturers.

Chapters 5 and 6 identify regional demand and production of semiconductor devices.

Chapter 7 presents the bottom levels of the demand waterfall, which are the resulting demand and production of semiconductor manufacturing equipment and materials.

Chapter 8 provides a summary of key issues and observations.

An investor or lender naturally will be interested in both the economic overview and resulting electronic equipment production forecast of Chapters 2 and 3, as well as the chapter presenting the perspective that matches his or her business interest.

Terminology and Definitions

Throughout this report, the terms "market," "consumption," "demand," "production," "output," "sales," and "revenue" have and will appear frequently. In addition, various economic terminology is used throughout. Precise definitions of these terms are given in the following paragraphs.

The terms "market," "consumption," and "demand" refer to the dollar value of products purchased within the specified geographical region, (e.g., North American and worldwide) regardless of where the products were manufactured.

The terms "production," "output," "sales," and "revenue" refer to the if-sold dollar value of products manufactured within the specified geographical region, regardless of where these products are purchased (i.e., purchased within the specified region or exported to another).

On the basis of the above definitions, assuming constant levels of inventory, worldwide production or sales equals worldwide demand or consumption.

The terms "real GNP" and "real GDP" refer to the gross national product and the gross domestic product of a country or major world region. The GDP is the total market value of all goods and services produced each year within the domestic borders of a country. The GNP equals the GDP plus the net of foreign investment income to domestic residents less income earned in the domestic market by foreign investors.

GNP/GDP also equals the sum of domestic demand plus exports minus imports. The three components of domestic demand are consumer spending, private fixed investment, and government spending.

The term "real" as applied to GNP, GDP, and other expressions refers to the value in constant prices prevailing in a reference year, which is 1982 for the US dollar. The term "nominal" as applied to GNP/GDP refers to the value at today's prices.

The terms "current account," "external account," or "external balance" refer to the difference between total exports and imports of goods and services, usually for one year.

The terms "private fixed business investment" and "private fixed nonresidential investment" both refer to investment in capital goods or capital spending by businesses and exclude residential investment. The term "private fixed investment" is the total of business capital spending and residential investment.

Dataquest Industry Classifications

Semiconductor Consumer Application Market Segments

Dataquest has categorized semiconductor consumers into the following six end-market application market segments:

- Data processing
- Communications
- Industrial
- Consumer
- Military
- Transportation

Semiconductor Product Classifications

Semiconductors are classified as either integrated circuits (ICs) or discrete devices. Within these classi- fications are further specific product definitions, outlined as follows, and illustrated in Figure 1-3:

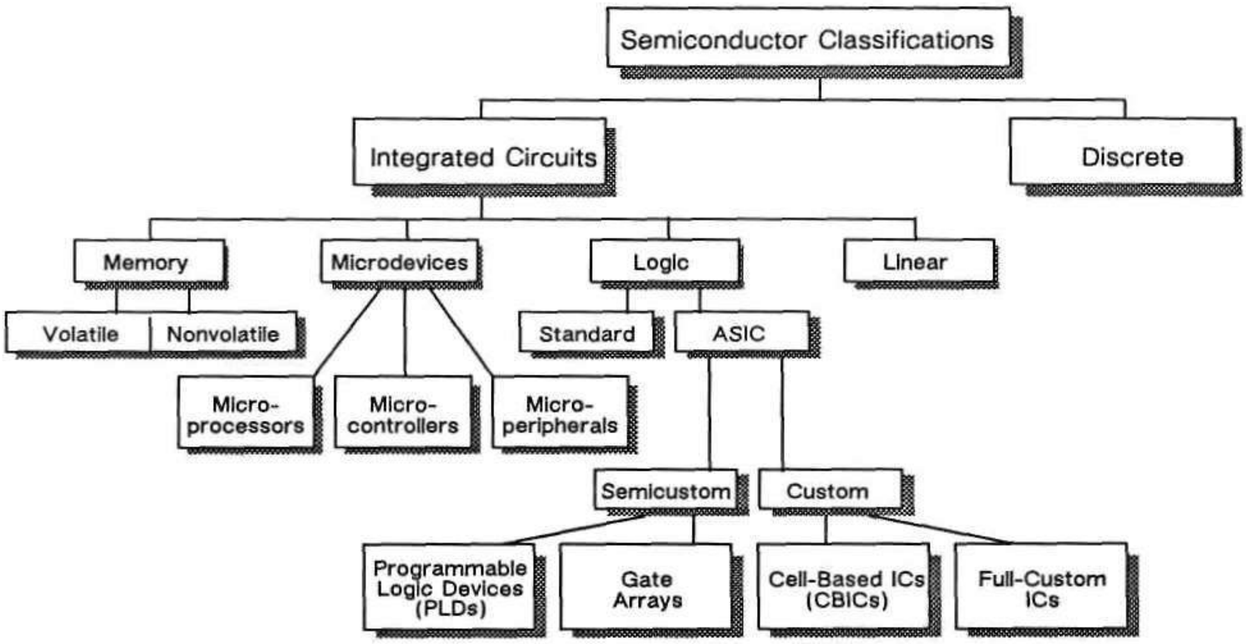
- Discrete devices are further classified as transistors, diodes, thyristors, optoelectronics, or other discrete devices.
- Integrated circuits are further classified into functions such as memory, microcomponents, logic, and analog.

All semiconductor devices are further classified by various process technologies, shown as follows:

- Bipolar digital—TTL, ECL, and others
- MOS—NMOS, PMOS, CMOS, and BiCMOS

Figure 1-3

Semiconductor Product Classifications



Source: Dataquest (August 1990)

CHAPTER 2

Critical Points in Understanding the Semiconductor Industry's Future

Critical to understanding the future of the semiconductor industry is an awareness of the events that have led the semiconductor industry to 1990 and knowledge of the electronics industry infrastructure that supports the semiconductor industry.

Historical Perspective: Events Leading to 1990

United States Launches the Semiconductor Industry

The launch of the semiconductor industry occurred when Bell Laboratories produced the first germanium transistor on December 23, 1947. By 1952, a number of companies in the United States were producing germanium devices commercially.

By the end of that decade, Texas Instruments (TI) had begun commercial production of silicon transistors. By then, the market topped $100 million in sales, primarily to the US Department of Defense (DOD) and to electronics companies for the manufacture of transistor radios.

Industry Expands to Worldwide Infrastructure

In 1959, Fairchild Camera and Instrument developed the planar technology for making transistors, which TI used in 1961 to produce the first ICs. Thus, the first decade of dynamic growth of the semiconductor industry was triggered.

Manufacturers worldwide began to integrate these new ICs into a variety of electronic-based products, and a worldwide chain of buyers and sellers to take semiconductors to market was established. Although the industry expanded to a worldwide infrastructure, the United States remained the dominant force in the infrastructure.

During the 1960s, semiconductor devices proliferated with small- and medium-scale integration (SSI, MSI). Logic families, such as the 7400 Series from TI, provided building blocks for electronic equipment and stimulated new electronic equipment designs. The demand for semiconductor memory began to rise in support of the logic building blocks. At the same time, major manufacturing technology advancements led to rapidly increasing device reliability and productivity. By the end of the decade, the industry was well on its way toward $2 billion in annual worldwide sales.

United States' Position in the Infrastructure Begins to Erode

The 1970s was the decade of low-cost electronic products. As the reliability and costs warranted, many companies used ICs to build such products as calculators, watches, or industrial, communications, and data processing equipment.

Early in the 1970s, US companies began to assemble their electronic products overseas to lower costs and expand their markets. European and Japanese markets, in addition to North American markets, became important to US manufacturers.

By the mid-1970s, US manufacturers were moving semiconductor production offshore to take advantage of lower costs and to be closer to the electronic assembly operations that had moved there earlier in the decade.

Metal-oxide semiconductor (MOS) ICs were the dominant products, and by the mid-1970s, large-scale integrated (LSI) devices were proliferating rapidly, further driving the low-cost electronic product era. As a result, worldwide industry sales were nearly $10 billion by 1979.

By the end of the 1970s, the semiconductor business was a worldwide industry with competition on an international scale. The emergence of very large-scale ICs (VLSIs) brought important new products such as microprocessors, read-only memories (ROMs), and erasable programmable ROMs (EPROMs). The age of personal computers and electronic games was born. That age was built on a whole new notion of super-low-cost electronics created by LSI and VLSI semiconductors. The low cost made the items price-sensitive and ideal for the low-cost structure of the offshore companies.

In fact, the offshore companies producing semiconductors for US industry were now proving to be capable competitors in all areas of manufacturing, as well as suppliers of low-cost products to the United States. Leadership of the semiconductor infrastructure that the United States had helped to create and had dominated now was being threatened.

Japan and Asia/Pacific Countries Begin to Dominate

Japanese electronic equipment producers seized upon US innovations in the 1970s and, leveraging their indigenous superior productivity, outproduced their US counterparts. Over the last 15 years, the very solution to the fundamental domestic competitive weakness—to move electronic product assembly offshore—has developed these offshore countries (Japan, South Korea, and Taiwan) into fierce domestic and international competitors. In the last half of the 1980s, these competitors gained the dominant share of world markets at all levels of the infrastructure that was built so impressively by the United States such a short time ago. For an example of Japanese dominance, see Figure 2-1. The strengths of Japanese and Asian companies are discussed further in Chapter 5.

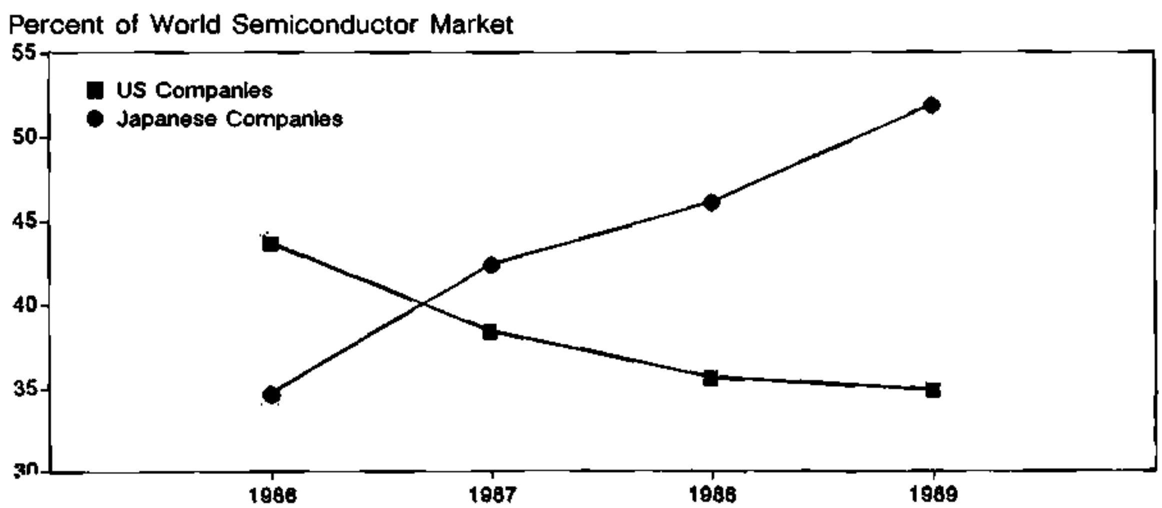
US Electronics Industry Faces a Critical Problem

As a result of losing their competitive edge, US companies are losing worldwide market share at all levels of the infrastructure; the loss now has become self-perpetuating. As the domestic companies lose share, they report declining growth rates and profits. These unfavorable results limit their access to investment capital, which limits the research and development (R&D) investment available to innovate the requisite new technologies that would regain a leadership position. As this process continues, the US semiconductor manufacturers face the following two-level problem:

- First, the US market for semiconductor devices is shrinking as a percentage of the worldwide semiconductor market (see Chapter 5).

Figure 2-1

US and Japanese Market Shares



Source: Dataquest (August 1990)

- Second, the Japanese and Asia/Pacific countries are gaining share of this shrinking worldwide market at the expense of the US producers' share, while not allowing much increase in US producers' share of their domestic markets.

This decline in competitiveness of the US electronics industry infrastructure is an issue of major concern to Japan, Europe, and other US trading partners for the following two reasons:

- The United States has been the primary source of semiconductor and system innovation since the beginning. Further competitive erosion could stall out that innovation and attract government and/or military interference in the market and/or promulgate adverse trade policies.

- Continued decline in the American electronics industry infrastructure could result in a significant recession of the US economy. Such a recession could eclipse the forecast consumption of a large volume of semiconductors and end products produced by Japanese and Asian manufacturers, leaving them with a severe drop in available market and significant overcapacity.

To sum up the conditions leading to 1990, the United States started the semiconductor industry, developed it into a huge worldwide industry, dominated it for several years, and now is at risk of becoming a minor player in the worldwide electronics market during the last decade of this century.

Electronics Industry Infrastructure: The Waterfall of Demand

The electronic industry infrastructure, of which the semiconductor industry is part, is made up of a complex chain of buyers and sellers working together to satisfy the worldwide demand for electronic products. This complex chain consists of several tiers, beginning with the demand for electronic equipment, continuing to semiconductor devices, and ending with the demand for semiconductor equipment and materials. Demand for various products flows through the buyer/seller chain from one level to the next, producing the cascading waterfall of demand shown in detail in Figure 2-2.

Knowledge of the infrastructure gives insight into how the various industry segments and the economy interact, specifically the following:

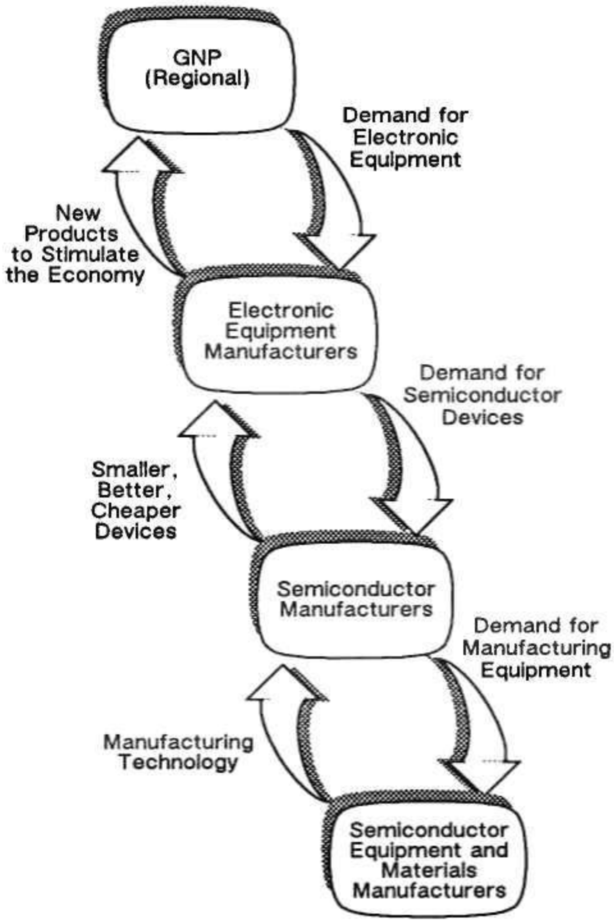
- How the demand of one industry segment affects the demand of the next industry segment

- How economic conditions affect the various industry segments

- How technology flows upward from one segment to the next and stimulates demand

Figure 2-2

Waterfall of Demand with Technology Flowing Upstream



Source: Dataquest (August 1990)

The Waterfall Headwaters: Capital Spending

As the worldwide economic climate changes, so does the worldwide demand for electronic equipment. The capital equipment spending sector of each region's economy has the largest influence on a region's demand for electronic products. This concept is developed in Chapter 4. Consumer and government spending have some impact, but to a much lesser degree. It is capital spending that forms the headwaters in the waterfall of demand.

Capital Spending Drives Electronic Equipment

Electronic equipment producers worldwide compete for their share of each region's demand. An equipment producer's ability to compete successfully in its domestic region or to export successfully to fulfill the demand of foreign regions depends largely on the economic climate of its domestic region. Economic factors such as exchange rates against other regions' currencies, relative interest rates, availability within the region of investment capital, and local labor costs determine the productivity and hence the competitiveness of producers located in a given region. The success of domestic producers in gaining share of the home region demand against importing competitors and in supplying foreign regions' demand via export determines the domestic producers' level of electronic equipment production.

Electronic Equipment Drives Semiconductor Demand

Electronic equipment production drives semiconductor demand. The supply to this demand can be of semiconductors produced within a local region or imported from other regions. The semiconductor production levels, profits, and resulting available investment capital of semiconductor companies within a region depends on their share of that region's total demand and their ability to export to fulfill demand from other regions. The success of a regional semiconductor manufacturer depends on many factors, but to a large extent, domestic economic conditions and access to foreign regions' demand are the key factors.

Semiconductor Production Drives Semiconductor Equipment

The resulting capital spending by regional semiconductor manufacturers creates the regional available market for the semiconductor equipment industry. Thus demand—driven by the worldwide economic climate and regional economic factors—begins with capital spending and flows down the waterfall until it reaches semiconductor equipment and materials establishing the waterfall of demand.

Technology Flows Upstream

In addition to demand flowing down the waterfall, technology flows upstream, as indicated in Figure 2-2. Technology provides the impetus for new products.

Manufacturing technology created by the semiconductor equipment manufacturers enables lower cost, lower power, and greater speeds in semiconductor devices. Competition in the semiconductor industry is based in part on manufacturing technology. Competitive attributes such as cost, size, and speed of a semiconductor device is dependent on several manufacturing factors, as follows:

- Yield—how many good devices can be produced in one manufacturing run—affects the costs.
- Integration—how many units of logic and/or memory can be contained in one device—affects both the size and speed of the device.
- Quality and turnaround time—additional factors that depend on manufacturing technology—affect every aspect of competitiveness.

Fundamentally, advances in manufacturing technology create the environment and the tools for continuing advances in semiconductor manufacturing. The productivity and competitiveness of any semiconductor manufacturer is critically dependent on access to state-of-the-art manufacturing equipment, which can come only from an economically and technically strong semiconductor manufacturing equipment industry.

Semiconductor manufacturers combined system design with manufacturing technology and produced semiconductor devices that have greater functionality at lower cost and with better reliability—for example, 32-bit microprocessors, application-specific ICs (ASICs), and 4Mb dynamic random-access memories (DRAMs).

New semiconductor devices allow the creation of new electronic equipment that has new functions, higher performance, and lower cost, and is physically smaller and more portable.

Creative new end systems open new end markets and stimulate end-product demand, thereby stimulating the economy.

Semiconductor Equipment Forms the Base

Figure 2-3 presents the worldwide forecast of electronics equipment production, the semiconductor production required to meet this equipment demand, and the capital spending required of the semiconductor producers to meet this semiconductor demand. Few may realize that 1989 resulted in worldwide electronic equipment production of $653.1 billion, which generated demand for more than $57.2 billion of semiconductor devices, resulting in $18.0 billion spent on semiconductor capital equipment. In other words, the $50.5 billion semiconductor equipment industry is the foundation of the $653.1 billion electronic equipment industry.

Summary

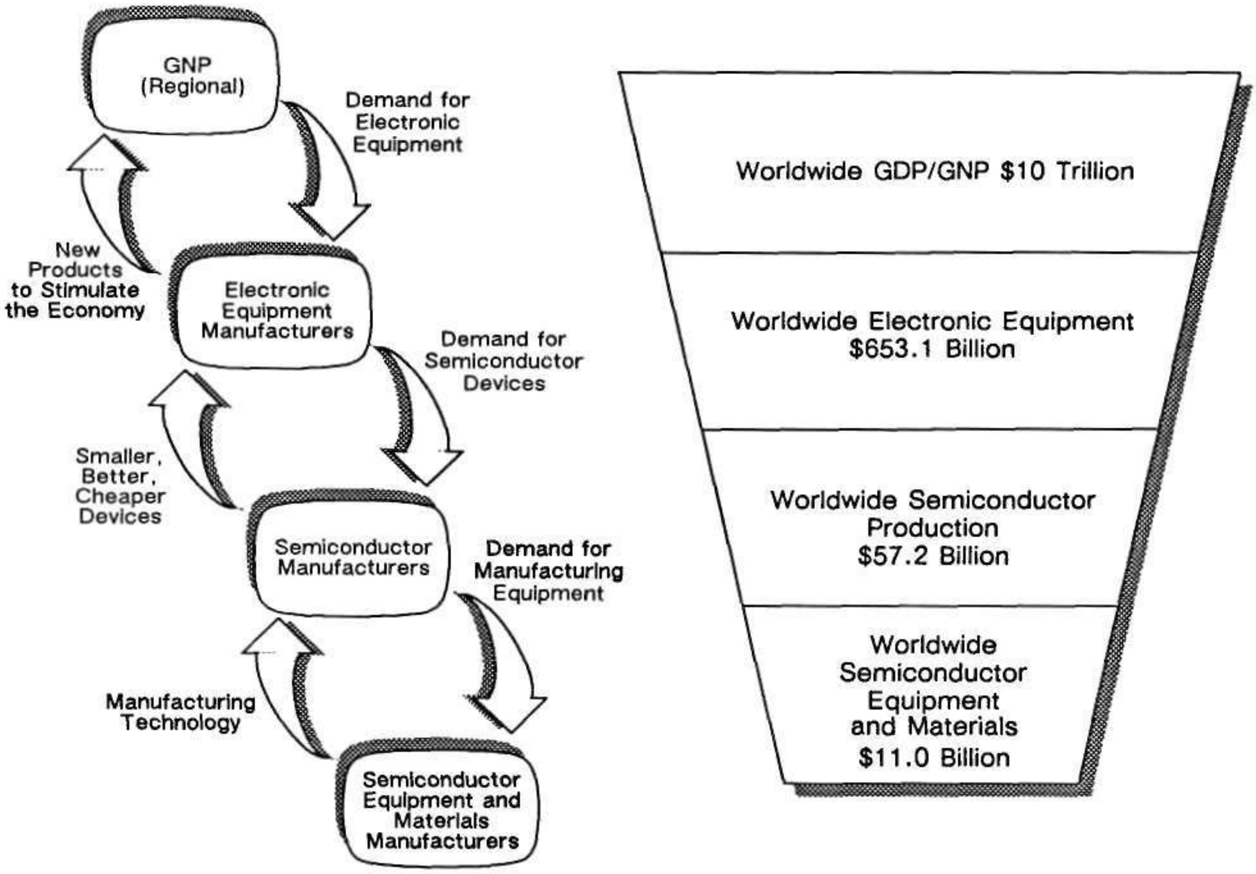
The following points are critical for developing an understanding of the semiconductor industry's future:

- US semiconductor manufacturers are at risk of exiting the stage in a play in which they designed, produced, and acted in the lead role.
- The US economy is dependent on its electronics industry.
  - The electronics industry is dependent on the semiconductor industry.
  - The semiconductor industry is dependent on the semiconductor equipment industry for necessary manufacturing technology.
- The worldwide economy is dependent on the worldwide electronics industry to produce new products to stimulate the worldwide economy.
  - The US electronics industry depends on both the US and worldwide economies.
  - The worldwide electronics industry is dependent on the global economy.

These observations are developed and discussed in succeeding chapters, beginning with global economic conditions and continuing through the production of semiconductor equipment and materials.

Figure 2-3

Base of the Waterfall



Source: Dataquest (August 1990)

CHAPTER 3

General Industry Climate 1989—The Year in Review

1989-1990: Off of the Escalator and into the Trough

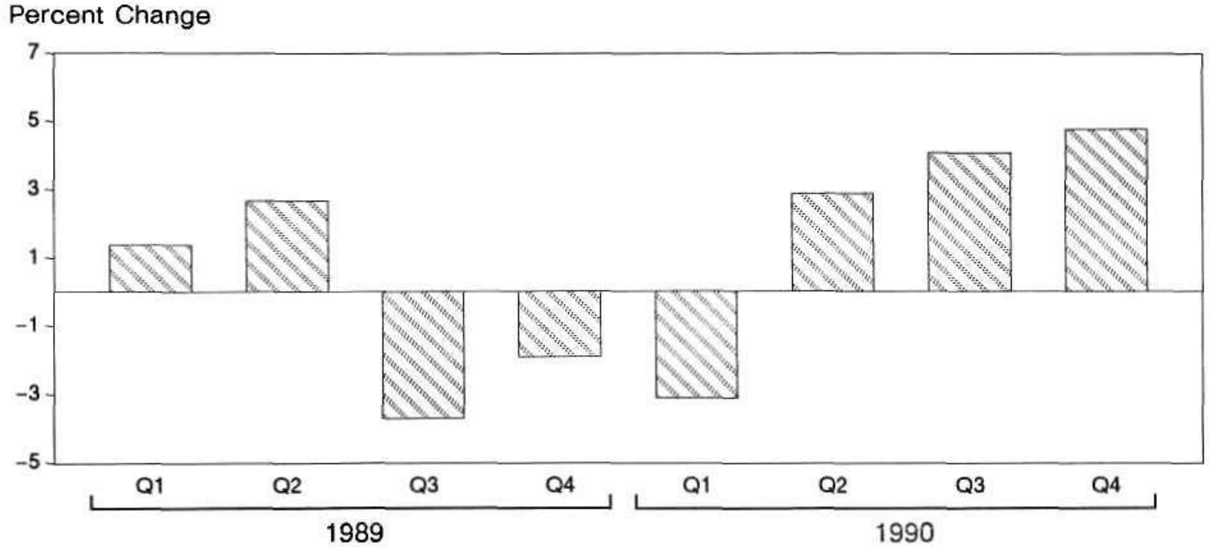
After realizing a growth rate of 33.0 percent in 1988, the semiconductor industry in 1989 posted positive growth rates in the first two quarters and then slumped into a recession in the third quarter (see Figure 3-1). Although industry growth rates for the third and fourth quarters of 1989 were negative on a quarter-to-quarter basis, only the fourth quarter posted a negative growth rate when compared with the fourth quarter of 1988. As a result, the industry posted a respectable 10.9 percent growth rate for 1989. First quarter 1990 was the last of three consecutive quarters of negative growth. Positive growth is expected on a quarter-to-quarter basis throughout the rest of 1990, but Dataquest estimates that the industry will realize a growth rate of negative 0.7 percent for 1990. Several factors influenced the performance of the semiconductor industry in 1989 and early 1990, including the following:

- Declines in real GNP growth rates
- Declines in consumer spending growth
- Declines in capital spending growth
- Declining growth rates for electronic equipment demand

The following paragraphs describe these factors and their effects on the semiconductor industry.

Figure 3-1

Quarterly Semiconductor Industry Growth Rates 1989-1990



Source: Dataquest (August 1990)

Economic Growth Eases

According to the International Monetary Fund, the real GNP growth rate for industrialized countries fell from 4.4 percent in 1988 to 3.5 percent in 1989. During that same period, consumer spending growth fell from 3.7 percent to 2.8 percent, and capital spending growth fell from 7.9 percent to 5.6 percent. Because the demand for semiconductors is a derived demand, driven by the demand for electronic equipment, declines in capital and consumer spending growth often translate to declining demand growth for semiconductors.

The following paragraphs briefly look at the economic performance of the four major industrial regions of the world.

US Economic Performance

Table 3-1 shows the actual and forecast GNP growth rates for selected countries from 1988 to 1991. Holding dollars constant, the US GNP growth rate was 3.0 percent in 1989, down from the 4.4 percent rate posted in 1988. On a quarterly basis, the GNP growth level fell from 3.7 percent in the first quarter to 2.5 percent in the second quarter. In the third quarter, the growth rate rebounded up to 3.0 percent. Finally, in the fourth quarter, a growth rate of only 1.1 percent was realized. GNP growth was 2.1 and 3.4 percent, respectively, for the first two quarters of 1990. According to economists at The Dun & Bradstreet Corporation, GNP growth is expected to be 2.6 percent in the third quarter of 1990 and 3.9 percent in the fourth quarter. D&B forecasts a 3.0 percent growth rate in GNP for the year.

Japanese Economic Performance

In 1989, real GNP rose 4.8 percent in Japan. Although lower than 5.8 percent growth in 1988, 1989 growth still was very respectable. The Japanese economy slowed because of weaker consumer spending, which was partly due to the imposition of a new sales tax and a deterioration of the Japanese trade surplus. Growth in business investment continued at a strong pace, expanding 17.7 percent in 1989, up from 15.5 percent in 1988. Business investment growth is expected to fall to approximately 10.0 percent in 1990. In addition, real GNP growth is expected to fall to 4.0 percent in 1990.

European Economic Performance

Taken as a whole, the four major European countries (France, Italy, the United Kingdom, and West Germany) experienced a real GNP growth rate of 3.4 percent in 1989, down from 3.8 percent in 1988. Of these four countries, only West Germany realized an increase in real GNP growth, from 3.6 percent in 1988 to 4.0 percent in 1989. In 1990, real GNP growth is expected to fall further to 2.8 percent.

Table 3-1

Annual and Forecast GNP Growth for Selected Nations
1988-1990
(Percent Change from Previous Year)

Country	1988 GNP	1989 GNP	1990 GNP	1991 GNP
United States	4.4%	3.0%	2.5%	3.4%
Japan	5.8%	4.8%	4.0%	3.9%
France	3.8%	3.7%	3.2%	3.4%
West Germany	3.6%	4.0%	4.0%	3.5%
United Kingdom	4.6%	2.3%	1.5%	2.5%
South Korea	11.3%	6.1%	5.5%	6.5%
Taiwan	7.3%	7.4%	6.5%	7.0%
Singapore	11.2%	9.2%	7.5%	7.0%
Hong Kong	7.3%	3.5%	4.0%	3.5%

Source: The Dun & Bradstreet Corporation

Asian Economic Performance

As in the other regions of the world, real GNP growth in Asia fell in 1989 from its 1988 levels. In South Korea, real GNP growth fell from 11.3 percent in 1988 to 6.1 percent in 1989. Taiwan experienced higher GNP growth, rising from 7.3 percent in 1988 to 7.4 percent in 1989. In Singapore, the double-digit GNP growth rate of 11.2 percent in 1988 gave way to a growth rate of 9.2 percent in 1989. Finally, in Hong Kong, the 1989 GNP growth rate of 3.5 percent was less than one-half of the 7.3 percent recorded in 1988. GNP growth rates throughout the region are expected to decline once again in 1990.

Electronic Equipment Slowdown

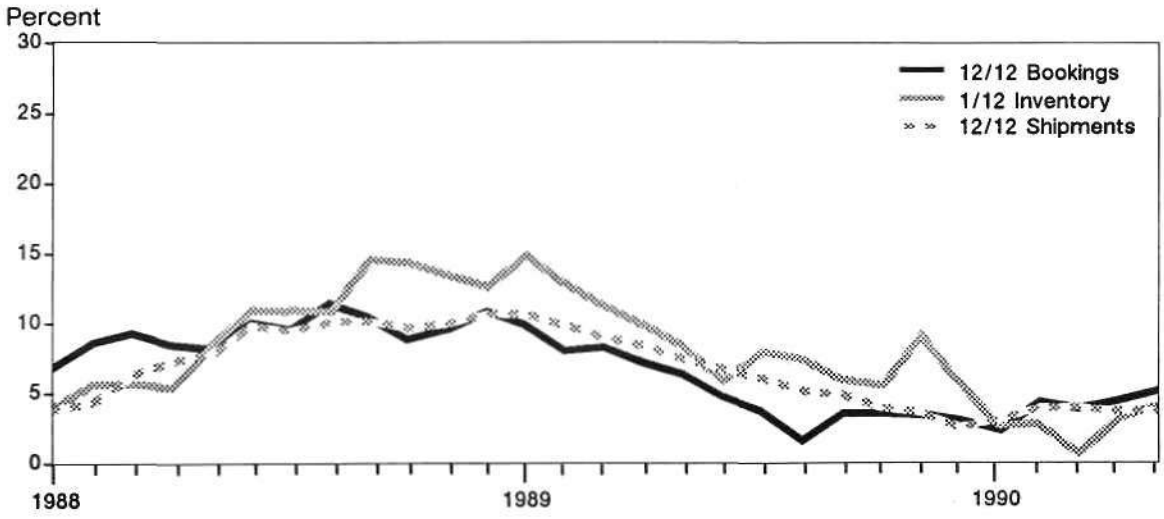
Monthly data from the US Department of Commerce (DOC) shows that bookings and shipments rates of change for the computers and office equipment, and electronic instruments segments generally declined through 1989 when measured on a 12/12 basis. The rate of change of growth in computers and office equipment shipments declined for 12 consecutive months, beginning in January 1989 with a 12/12 growth rate of nearly 11.0 percent, before bottoming out in December 1989 at 2.8 percent (see Figure 3-2). At the same time, 12/12 bookings showed continuous decline from 11.1 percent in December 1988 to 1.9 percent in August 1989. More disturbing than the mere declines is the fact that computer and office equipment orders, on an annualized basis, have fallen from a growth rate of approximately 10.0 percent in January 1989 to only 4.0 percent in March 1990.

1989 Forecast and Outcome

In a February 1989 newsletter entitled "Worldwide Semiconductor Outlook: First Quarter 1989," Dataquest forecast modest growth in the semiconductor industry for the first two quarters of 1989 followed by three negative quarters beginning in the third quarter of 1989, as memory prices fell and the US economy softened slightly. In reality, the worldwide semiconductor market grew 1.4 and 2.7 percent, respectively, in the first two quarters of 1989. As we predicted, the third and fourth quarters showed negative growth, declining 3.7 and 1.9 percent, respectively, on a worldwide basis. The overall, worldwide year-to-year growth rate was 10.9 percent in 1989.

Figure 3-2

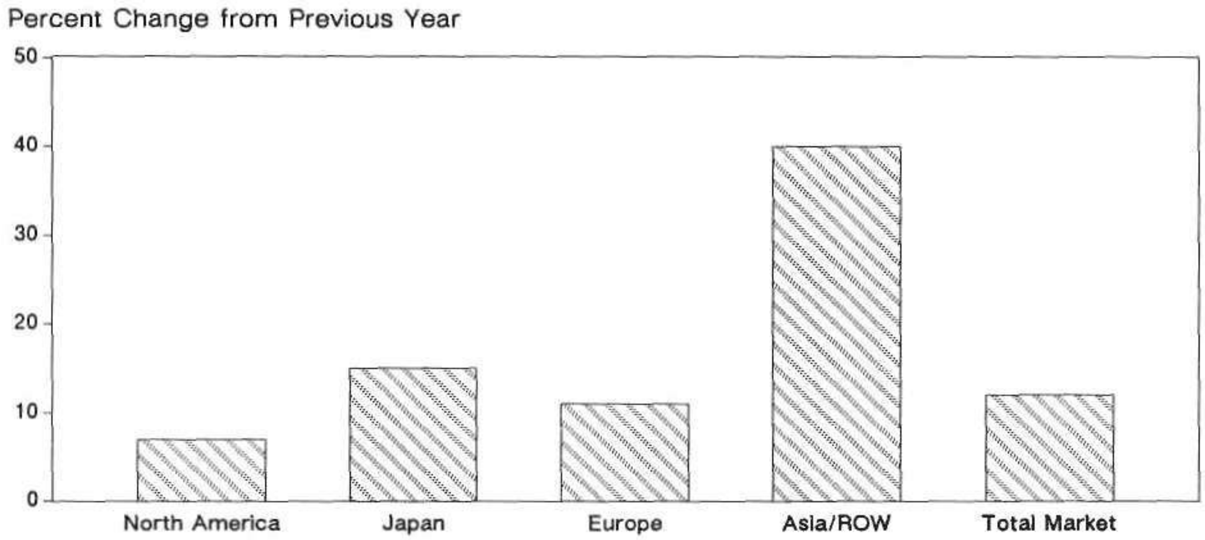
Computers and Office Equipment Rate of Change 1988-1990



Source: US Department of Commerce

Figure 3-3

Semiconductor Production Growth by Region—1989



Source: Dataquest (August 1990)

Performance of the North American and European markets mirrored that of the worldwide market. Both regions showed positive, albeit moderate, growth in the first half of 1989, followed by two quarters of negative growth in the second half of the year. The Japan and Asia/Rest of World (ROW) regions differed slightly in their performance. In each of these regions, the first quarter was one of negative growth, followed by a positive second quarter, and negative growth in the third and fourth quarters. All four major regions experienced at least moderate growth for the year, however, as is depicted in Figure 3-3.

1989 US Book-to-Bill Analysis

As expected, the US semiconductor book-to-bill ratio generally followed the industry trend of slow first-half growth followed by negative second-half growth (see Figure 3-4). Beginning with a ratio of 1.02 in January 1989, the book-to-bill ratio remained above parity until June, when it fell to 0.98. The ratio climbed above parity again in December, and has remained above 1.0 since that time. As stated previously, US electronic equipment sales growth slowed throughout 1989. When combined with tighter inventory controls, the result was a decline in semiconductor orders in the second half of 1989.

US semiconductor billings for the first half of 1989 increased 20.3 percent over the same period in 1988. During the second half of the year, low inventory levels, particularly in non-DRAM products, caused an increase in spot purchases, which increased "turns" business. The effect of increased "turns" business is usually more intense competition and price pressure, which only makes market declines more severe. DRAM price declines also contributed to the decline in the US market.

Despite the declining book-to-bill ratio, monthly billings showed positive year-to-year growth for each month in 1989. In fact, only the fourth quarter of 1989 showed negative growth on a year-to-year basis.

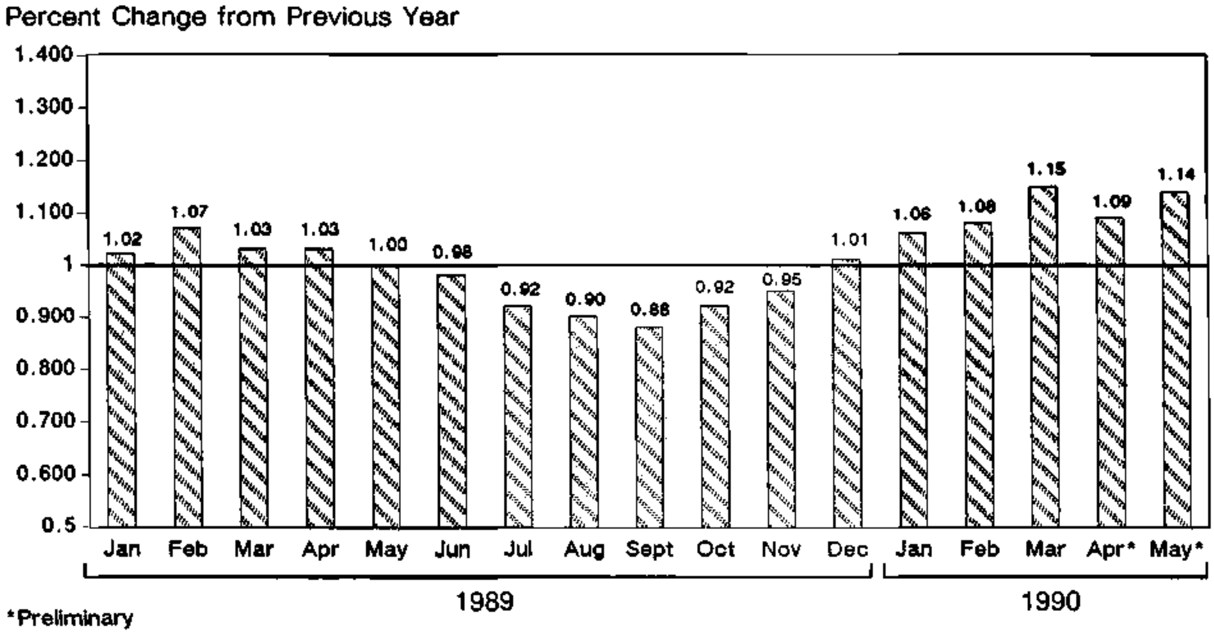
Product Summaries

Analog ICs

The year 1989 was a tough one for many analog suppliers. More than a tough year, it was a historic year in which analog IC segments experienced a significant downturn while many of the digital segments had a softer landing. This effect was the opposite of past trends where the stability of the analog IC market had made it more insulated from market deterioration than the more volatile digital IC market.

Figure 3-4

US Semiconductor Book-to-Bill Ratio
1989-1990



Source: Dataquest (August 1990)

During 1989, unit sales of analog ICs increased while average selling prices (ASPs) declined, leading to a very weak revenue growth for the year. A significant ASP decline in commodity linears (largely op amps and voltage regulators) starting in mid-1988 flattened revenue growth in 1989 despite the fact that unit growth continued through 1988 and 1989. Consumer-specific IC consumption declined as the consumer market for VCRs, camcorders, CD players, and other entertainment products softened. Because consumer products represent 40 percent of analog IC sales, the softness of the consumer market impacted the analog IC market significantly.

Dataquest has observed digital signal processing (DSP) entering into more mixed-signal products, replacing analog signal processing. One product segment that showed significant growth in 1989 was that of delta sigma ADC converters. Several new delta sigma converters were introduced in 1989, many for microprocessor (MPU)-based and digital/audio applications. The growth of this market is driven by growth in digital/audio systems, which also has driven substantial unit growth in digital-to-analog converter (DAC) markets. Palette DACs and digital audio DACs were two of the more noticeable winners in the 1988 market. In 1989, an avalanche of competitive products brought down ASPs, severely impacting the data converter segment.

The year was marked by a trend toward mixed-signal ICs. This trend is driven by continuing growth in digital products, which need mixed-signal ICs to simplify complex interfaces. Perhaps the biggest disappointment of 1989 was the fact that mixed-signal ASICs did not live up to the tremendous media attention and marketing hype. The revenue still is relatively small, profits are nonexistent, and tool and test issues cloud future growth. Companies that have experimented with mixed-signal ASICs have not fared well. Dataquest has identified a trend among original equipment manufacturers (OEMs) away from ASICs toward application specific-standard products (ASSPs). As mixed-signal ICs gain popularity, these more complex ICs, with increased analog integration, will reverse the general trend toward sagging ASPs, providing increased analog revenue growth and bringing unit growth more into line with revenue. Despite this upward pressure on selling prices, Dataquest expects commodity linear op amps, regulators, and interface ICs to continue their downward trend.

ASICs

In 1989, the ASIC market grew 10.9 percent, slightly below the growth rate of 12.0 percent posted for the total semiconductor market. Gate arrays dominated the market, growing from 40.0 percent of the 1988 ASIC market to 42.0 percent in 1989. The next largest 1989 ASIC market was full-custom ICs with 31.0 percent, followed by cell-based ICs (CBICs) with 18.0 percent and programmable logic devices (PLDs) with 9.0 percent.

Gate arrays offer many advantages over full-custom ICs and CBICs. Key gate array advantages include quicker time to market, lower risk, and lower design cost. In 1989, gate arrays won the design-win battle over CBICs. However, 1989 gate array pricing was cutthroat as suppliers battled for market share. The aggressive pricing was true even in submicron geometries. In the past, Dataquest observed price premiums for next-generation parts; this no longer seems to hold true. Because of disappearing price premiums, profits in the gate array market were very slim despite a 16.0 percent revenue growth. Through gate arrays, ASIC silicon has become a commodity item, and ASIC tools are becoming commodity items. The only way suppliers are able to differentiate themselves is through their libraries of application-specific building blocks. In the future, the companies with strong applications experience are the ones that will be profitable.

The use of CBICs has been limited by the dominance of gate arrays to high-volume, very high performance, or special functions such as mixed-signal applications. However, in the development of standard products, the CBIC is replacing the full-custom IC as the accepted design methodology.

Simple PLDs (GAL- and PAL-type devices) are no longer outperforming the market; they are now growing with the market. As the popularity of bipolar PLDs wane, the rapidly growing CMOS PLD market is becoming quite crowded. The market for complex PLDs (e.g., FPGAs) is showing tremendous growth and is expected to nearly double in 1990. The growth of this market is equivalent to that of the MOS gate array market at a similar stage in the product life cycle. This market remains wide open, because no standards have been developed yet.

Memory Products

In 1989, the memory market continued to dominate the worldwide semiconductor market. Despite tumbling DRAM prices, the MOS memory market grew an astonishing 45 percent in 1989. Were it not for the strength of the memory market, in particular the inflated DRAM prices in the first half of the year, the slowdown the industry experienced in late 1989 and early 1990 could have been much worse.

Perhaps the biggest story of 1989 was the DRAM shortage and subsequent oversupply situation. At the beginning of 1989, a series supply shortage existed for 256K and 1Mb DRAMs. First-tier Japanese DRAM manufacturers reaped high profits with their strategy of managing supply to control prices. As the year continued, however, the supply shortage transformed into an oversupply situation. As demand slowed and South Korean and US manufacturers brought new products on-line, supply was able to meet demand in the third quarter before resulting in an oversupply of DRAMs. As a result of this situation, DRAM prices fell dramatically from their earlier levels. Volume prices for 1Mb DRAMs, for example, fell from approximately $18 in the first quarter to the $7 to $8 range by year's end. One of the more significant developments that arose in the DRAM market during 1989 as a fallout of the shortage was Samsung's growth as a DRAM supplier. Samsung was able to take advantage of the supply management tactics of the larger vendors and the market slowdown to become the number three supplier in the DRAM market. Another fallout of the DRAM shortage was the formation of U.S. Memories, a consortium formed to provide the United States with a domestic source of DRAMs. A full review of the rise and fall of U.S. Memories is provided in the section entitled "Key Industry Events and Issues." In 1989, the memory market proved itself to be a very volatile market, one that can quickly change from a shortage to an oversupply situation.

During 1989, we saw the early introduction of the 4Mb DRAM. This introduction marked the emergence of 0.8-micron CMOS line geometries into full-production lines. Hitachi and Toshiba were the unquestioned early leaders in the production of 4Mb DRAMs.

In slow SRAMs, we observed significant price degradation following a three-month lag behind DRAMs. This pricing relationship is due to the close ties between SRAMs and DRAMs from a manufacturing standpoint. As the oversupply situation developed in the DRAM market, manufacturers shifted capacity toward other devices including slow SRAMs, PSRAMs, nonvolatile memories, and ASICs. Both types of SRAMs are tied to DRAM capacity, although slow SRAMs are more closely tied. Therefore, although we saw price erosion in the fast SRAM market, it was not as severe as that in the slow SRAM arena.

The markets for specialty memories became quite crowded in 1989. In the market for SRAM-based deep first-in, first-out (FIFO) products, for instance, the number of suppliers grew to 18, servicing a market that totaled only $70 million. In the same way, the number of suppliers to the dual-port SRAM market grew to 9—quite a few for an $18 million market. As a result, Dataquest observed significant price erosion in these markets.

In 1989, BiCMOS memories also continued to grow. The three market leaders were Hitachi, National Semiconductor, and Fujitsu. Most of the main users of BiCMOS memory are suppliers of supercomputers and large mainframes that use BiCMOS SRAMs as main memory or large secondary caches. Unfortunately, 1989 also saw the death of Saratoga Semiconductor, a US supplier of BiCMOS memories.

Microcomponents

In 1989, the worldwide market for microcomponent products slightly outperformed the total semiconductor market with a growth rate of approximately 13 percent. The year was highlighted by several significant product trends.

The major battle lines in the reduced-instruction-set computing (RISC)-based market have formed around four camps: Intel's i80860, MIPS Computer Systems' R3000, Motorola's 88000, and Sun's SPARC architecture. Both Sun and MIPS were busy licensing their architectures to eager semiconductor vendors. Toshiba announced an agreement to team up with Sun Microsystems to develop low-cost, higher-performance computers using the SPARC architecture and SunOS UNIX operating system. LSI Logic, which teamed up with Sun to develop the SPARCstation 1 single-board RISC system, announced in early 1990 that it is producing a SPARC chip set that will facilitate the production of SPARC-compatible workstations. In 1989, MIPS Computer Systems announced long-term agreements with both NEC and Siemens to license its RISC microprocessors for manufacturing, marketing, and support worldwide. Currently, the major battle for dominance is between SPARC and MIPS architectures. With a total of 12 vendors (6 embracing each architecture), the competition for RISC sockets has become very intense.

Perhaps the major driving force in the microcomponent industry in 1989 was the realization that PC-related products can offer significant volumes and revenue. This fact was most visible in the market for PC chip sets. During the past two years, the PC logic chip set market has been the fastest-growing segment of the microcomponent market. Worldwide, there were only 6 PC logic chip set vendors in 1987. In 1990, there are more than 30. Dataquest believes that the rapid increase in new entrants and capacity has carried this market to the point of saturation. We expect this saturation to lead to aggressive price competition, causing vendors to look for penetration of these products into new applications and markets. We believe that this rapid market saturation is bound to be repeated in each of the PC peripheral chip set markets—logic, graphics, communications, mass storage, modem, and fax—as established chip set and semiconductor companies follow one another into these obvious product-line extensions. At the same time, the apparently low barriers to entry invite many new participants. The graphics chip set market already is showing signs of saturation, marked by severe pricing pressure.

Another PC-related market that has exhibited increased competition and drawn increased media attention is the floating-point coprocessor market. Traditionally, Intel, Motorola, and Weitek have dominated the market for floating-point units (FPUs). For potential entrants to the compatible coprocessor market, the current low level of penetration into available sockets, combined with artificially high prices and margins, is an attractive inducement to entry. Until recently, no vendors have offered parts that are plug-compatible with Motorola or Intel devices. Weitek has achieved success in the high-end coprocessor market, but has not offered plug compatibility to the Intel architecture. In 1989, two start-ups, Cyrix Corporation and Integrated Information Technology

(IIT), introduced devices that are plug-compatible with Intel's 80X87 products. As these start-ups begin to challenge Intel's dominance in this market, we have witnessed increased marketing hype and price cutting by Intel in an effort to protect its market share.

Many manufacturers, including Intel and most RISC vendors, have entered the 32-bit embedded control market. In general, the embedded control market is easier to compete in than that of reprogrammable processors, which often require name recognition and binary compatibility with existing products. The key to competition in the embedded control market is the cost effectiveness of the part, which includes price, space taken up on the board, the number of required peripherals, and the required software. As is true with many other products, however, there is a significant lag period between the introduction of a product (32-bit processors in this case) and the availability of sockets and large sales volumes. Unfortunately, vendors in the 1989 and 1990 market for 32-bit embedded control are caught in this lag period. At this time, only a limited number of available sockets exist, and revenue is very low. Dataquest believes that this situation will change, but probably not until 1991. In April 1989, Motorola introduced the industry's first 32-bit microcontroller (MCU). Motorola is the company to watch as the 32-bit embedded control market heats up.

Key Industry Events and Issues

U.S. Memories

On Wednesday, June 23, 1989, a new company called U.S. Memories announced its intention to become the fifth US-owned, noncaptive supplier of DRAMs. The company was to be a jointly owned venture funded initially by seven major US electronics and semiconductor companies. The companies contributing seed money to the start-up were AMD, DEC, Hewlett-Packard, IBM, Intel, LSI Logic, and National Semiconductor.

The new company was headed by Sanford Kane, who resigned from his position as vice president of technology at IBM to become the president and CEO of U.S. Memories. The new entity hoped to meet its $1 billion funding requirement and select a site by the end of 1989. The company stated a goal of building a wafer fabrication facility that will begin full-volume production of 4Mb DRAMs by the first half of 1991. However, between U.S. Memories and its vision of high-volume, leading-edge DRAM manufacturing in the early 1990s existed a number of hurdles. These hurdles included successfully addressing potential antitrust barriers, convincing other systems and components companies that they have a vested interest in participating in the new venture, and overcoming a late start in the 4Mb DRAM market, particularly in relation to Japanese competitors.

Indeed, the antitrust issue was raised and was a source of great controversy in Washington D.C. One of the a priori conditions of U.S. Memories' formation was the modification of the Sherman Antitrust Act of 1890 so that US companies can more easily form manufacturing consortia. Although existing legislation allows consortia to engage in R&D activities and provides immunity from antitrust damages for export-only consortia, these measures do not address the issues raised by U.S. Memories. A number of bills under consideration in the House of Representatives would apply some measure of antitrust immunity to manufacturing consortia.

In the end, the funding, site selection, and antitrust obstacles became moot issues. On January 15, 1990, Sanford Kane announced the dissolution of the consortium. Mr. Kane explained that U.S. Memories was a strategic approach that could have worked, but with the exception of solid support from IBM and DEC, there was inadequate response from the rest of the computer industry.

In forming U.S. Memories, Kane successfully mastered the challenges of producing a business plan, obtaining an agreement with IBM to license its 4Mb DRAM design and process technology, narrowing down the selection of a plant site, and obtaining a favorable opinion regarding antitrust issues. But in the end, he could not convince enough DRAM users to cumulatively invest $500 million and guarantee to purchase at least 50 percent of USM's DRAM output. Even on its deathbed, USM made one final effort with a revised plan wherein the total equity investment required from the participating computer manufacturers was scaled down to $150 million. However, the purchase guarantees rose from 50 percent of USM's output to 75 to 80 percent of the output, and an additional $200 million of equity was to be raised from external institutional investors. This plan was submitted to 11 interested companies—the 7 original investors, and 4 others: AT&T, Compaq Computer, NCR, and Tandem

Computers. At a meeting on January 10, the revised proposal could not garner sufficient support, so the decision was made not to continue with U.S. Memories.

The speakers at the January 15 press conference said that the impetus for the formation of a U.S. Memories came from an "urgent request" from the AEA and SIA that the domestic computer industry wanted an indigenous company that could supply 40 percent of its DRAM requirements within a reasonable time. USM's mission was, simply put, to provide a domestic source for an assured, stable supply of DRAMs while also offering an attractive return on investment. The computer companies' cry for a domestic supply of DRAMs was driven by the difficulties experienced from 1987 through the first half of 1989 when 1Mb DRAMs were scarce and expensive. However, by the time USM's funding effort had gained momentum, the bottom had dropped out of the 1Mb DRAM market, and the industry was flooded with parts. The passion for a domestic DRAM supplier had waned, and the computer manufacturers had forgotten about last year's problems.

Dataquest is aware of other ongoing efforts to establish a sizable US-based memory capability. Approaches such as that taken by Texas Instruments with its vendor alliances may also serve as a more workable model. We believe that a series of alliances between memory consumers and major US-based memory producers that are willing to make significant investment will occur in the 1990s, albeit in more focused relationships.

SEMATECH

In August 1987, SEMATECH announced its incorporation. The SEMATECH mission statement is both concise and powerful: "To provide the US semiconductor industry the domestic capability for world leadership in manufacturing." SEMATECH defines its role in fulfilling its mission in terms of "the three Ds and a T": Define, Develop, Demonstrate, and Transfer, which are described as follows:

- Defining and coordinating programs—Along with the collective resources of its member companies, SEMATECH analysts perform competitive analysis aimed at identifying critical manufacturing technologies required to reach the consortium's goal of worldwide manufacturing leadership for the US industry. SEMATECH further defines its role as "prioritizing resources for maximum impact." This impact would come through programs that address "show stoppers" (critical tools and materials to which the United States is in danger of losing access), "key enablers" (tools and methods that would give member companies the largest advantage in the shortest time), and "high-risk/high-return manufacturing approaches."
- Developing world-competitive manufacturing capability—From its definition of programs, SEMATECH creates equipment specifications, selects suppliers with which it contracts for the delivery of equipment based on its specifications, shares in the development work of its SEMI/SEMATECH companies, and sets standards for manufacturing equipment integration.
- Demonstrate capability—SEMATECH's Austin, Texas, fab is charged with providing engineering characterization and manufacturing proof for the equipment and materials developed under its direction. The consortium's means of providing "proof of manufacturability" are based on its "manufacturing demonstration vehicles" (MDVs), the 4Mb DRAM and 64K fast SRAM processes provided by IBM and AT&T, respectively.
- Technology transfer—The final and most critical ingredient to SEMATECH's success rests in its ability to document its projects and to develop training programs that successfully transfer the derived technology benefits to its member companies. Essential to successful technology transfer is the participation in SEMATECH from the member companies.

As the preceding explanation of the SEMATECH philosophy makes clear, SEMATECH does not see itself so much as the originator of manufacturing technology R&D but rather as the coordinator and facilitator of such efforts by an existing US semiconductor equipment and materials vendor base. Where the rubber meets the road in the SEMATECH program is through the allocation of the consortium's $200 million-a-year budget to this vendor base in the form of contract awards. Currently, most of these contracts either are Joint Development Projects (JDPs) aimed at the development of new manufacturing techniques, materials and equipment, or Equipment Improvement Programs (EIPs) aimed at the improvement of existing tools.

Up to the beginning of 1989, the largest portion of the SEMATECH budget was devoted to the construction of facilities and the purchase of capital equipment. With its clean room constructed and the majority of its permanent employees and member-company assignees in place, SEMATECH's gathering of momentum has been obvious through 1989. Less than 15 months after the selection of its Austin, Texas, site, SEMATECH announced the first run of functional 64K SRAM silicon in March 1989, thus establishing its initial baseline process as outlined in its Phase I goals. The increased funding that became available for joint development and equipment improvement programs at the start of last year is clearly reflected in the pace of SEMATECH contract awards observed by Dataquest since the first contracts were awarded in May 1989.

An indication of SEMATECH's contract priorities can be found in its 1989 Operating Plan. Based on its 1989 goals, SEMATECH identified the following release schedule for external development contracts:

- First quarter: e-beam mask making system, I-line resists, planarization technology
- Second quarter: deposition systems, DUV steppers and resists
- Third quarter: lithography cluster
- Fourth quarter: inspection systems

Viewed against these priorities, Table 3-2 provides a chronological look at SEMATECH's contract awards from May 1989 to April 1990. The number of contracts since fall 1989 should probably serve as a good indicator of future SEMATECH contract activity, because in its 1990 Operating Plan, SEMATECH stated that "Labor, operating, and facilities costs will have reached steady-state by the end of FY 1989" (SEMATECH's fiscal year begins in October). At present, between 35 and 40 percent of the total SEMATECH budget is dedicated to development contracts.

Litigation

In 1989, a number of lawsuits were filed as semiconductor manufacturers attempted to protect their intellectual property. It has become obvious that intellectual property, marked by patents, is a very valuable asset in today's semiconductor market. The two most prominent court cases of 1989 involved lawsuits filed by Intel and Motorola against NEC and Hitachi, respectively.

After a legal battle that lasted nearly five years, Intel's suit against NEC for infringing on Intel's copyright claim to its 8088/86 microcode was resolved in 1989. In February 1989, Judge William Gray decided that although Intel had a valid copyright claim to its microcode, it forfeited its copyright to a lack of diligence in monitoring the affixing of copyright notices. The big decision, however, was that NEC was held to be innocent of copying Intel's microcode in its V-Series microprocessors. By December 4, 1989, all outstanding issues in the litigation had been resolved. As part of the settlement, NEC's claims for unfair competition, which were to come before the court in January 1990, have been dismissed. Further details of the settlement were not disclosed.

In January 1989, Motorola filed a lawsuit against Hitachi charging patent infringement and unfair competition that Motorola claimed began after it granted Hitachi a patent license for certain devices in 1986. Motorola's position was that Hitachi's new H8 microcontroller series infringed on at least four Motorola patents. Approximately one week after Motorola's charges, Hitachi responded by filing a patent infringement suit against Motorola. Hitachi alleged infringement of one of its patents by Motorola's 68HC11 8-bit microcontroller and countered that not only did its H8 not infringe on any Motorola patent, but that the device was covered by a patent license. In June, Hitachi filed an amendment to its pending lawsuit against Motorola to include allegations of patent infringement by Motorola's 68030 microprocessor.

On March 29, 1990, in a US district court in Austin, Texas, Federal Judge Lucius Bunton decided that Hitachi's H8 microcontroller was not licensed under the parties' 1986 Patent License Agreement; consequently, Hitachi committed patent infringement on three of Motorola's patents. Hitachi, therefore, was ordered to cease selling the H8 for the life of the affected patents and to compensate Motorola in the amount of $1.9 million. The judge also ruled, however, that Motorola infringed on an Hitachi patent and therefore was barred from marketing or selling its 68030 microprocessor for the duration of the patent; Motorola thus was required to pay Hitachi

Table 3-2

SEMATECH External Development Contracts
May 1989 to April 1990

Contract Date	Contract Partner	Program Type	Technology Focus
May 1989	ATEQ	JDP	Submicron reticle and mask exposure system
May 1989	GCA	EIP	I-line steppers
May 1989	GCA	JDP	Optical wafer stepper
May 1989	HP	JDP	Test chips
May 1989	Westech Systems	JDP	Global planarization processes
May 1989	SemiGas Systems	JDP	Ultrapure gas management systems
May 1989	Union Carbide	JDP	Ultrapure gas management systems
May 1989	Wilson Oxygen	JDP	Ultrapure gas management systems
July 1989	Eaton	JDP	Sputtering cluster tool
August 1989	NCR	JDP	Advanced isolation
August 1989	Nat'l. Inst. of Standards and Tech.	JDP	Metrology standards
Sept 1989	Sandia Nat'l. Lab	TAA	Establishment of Semiconductor Equipment Technology Center (SETEC)
Nov. 1989	Lam Research	EIP	Metal etch systems
Dec. 1989	Texas State Tech. Inst./ Center for Occupational Research and Development	TAA	Manufacturing specialist training program
Dec. 1989	Silicon Valley Group	JDP	Advanced photoresist processing
Dec. 1989	KLA	JDP	Wafer defect detection
Dec. 1989	ORASIS	JDP	Wafer defect detection
Dec. 1989	Oak Ridge Nat'l. Lab	TAA	plasma etch technology
Jan. 1990	Angstrom Measurements	EIP	Critical dimension measurement systems
Jan. 1990	Lam Research	JDP	Electron cyclotron resonance (ECR) CVD
Jan. 1990	University of Cincinnati	JDP	Plasma etch technology
Jan. 1990	ASTeX	JDP	Plasma etch technology
Feb. 1990	Ion Implant Services/Genus	TAA	High-energy implantation technology
Mar. 1990	Hampshire	JDP	Soft X-ray lithography
Mar. 1990	Drytek	JDP	Low-temperature plasma etch
April 1990	Applied	EIP	Dielectric CVD

JDP—Joint Development Project
EIP—Equipment Improvement Project
TAA—Technical Assistance Agreement
Source: Dataquest (August 1990)

$500,000 in damages. Following the decision, the judge quickly granted Motorola's request for a stay of the injunction on the 68030. At this point, both parties have the option of appealing the decision or negotiating a settlement.

A number of other lawsuits were filed in the industry in 1989 and early 1990. Although none of these cases has received the media attention that was given to the aforementioned cases, they are equally significant as semiconductor vendors struggle to protect their intellectual property and market share. In May 1989, AMD charged that two patents recently issued to Brooktree Corporation for digital-to-analog converter functions are not inventions within the meaning of US patent laws. AMD's effort to invalidate the Brooktree patents is the latest development in a litigation process that has continued since 1988. The dispute concerns color palette ICs produced by the two companies. Brooktree claims that AMD's devices infringe on its mask works, but was denied a restraining order against AMD following a hearing in November 1988.

In October, National Semiconductor announced that a patent infringement suit filed in 1985 against Linear Technology had been settled. The suit claimed that Linear had infringed on ten National patents, all related to analog products. Under the terms of the settlement, Linear has agreed to pay $3 million in return for irrevocable licenses, releases, and a comprehensive ten-year binding arbitration agreement. The case had just gone to trial in March 1989 when an opportunity arose to settle the case on mutually acceptable terms.

SGS-Thomson began 1990 with two new lawsuits against Dallas Semiconductor and Hyundai. In January, SGS-Thomson announced that it had filed a patent infringement suit against Dallas Semiconductor. At issue is the alleged infringement of SGS-Thomson's patents pertaining to battery-backed memory devices. License discussions between the two companies had recently broken down. In February, SGS-Thomson brought suit against Hyundai for patent infringement against SGS-Thomson's patents on DRAMs and SRAMs. The company had tried unsuccessfully for 18 months to conclude a licensing agreement that would provide compensation for Hyundai's use of SGS-Thomson's intellectual property.

Two other suits have been filed by Intel as the company tries to protect its market share in the floating-point coprocessor market. In February 1989, Intel filed suit against ULSI System Technology for developing products that substitute for Intel's 80387 math coprocessor through the "theft and misuse of Intel's proprietary information" pertaining to the 80386 microprocessor, the 80387 coprocessor, and Intel's i80860 64-bit microprocessor. Also, in April 1990, Intel filed a complaint against AMD, claiming that AMD has infringed on microcode copyrights on the Intel 80287 math coprocessor. Intel's action followed a notice by AMD stating that they have incorporated the Intel microcode into a coprocessor that AMD plans to announce soon.

A list of notable 1989 and 1990 lawsuits appears in Table 3-3.

Table 3-3

Litigation: 1989-1990

Plaintiff	Defendant	Date Filed	Subject	Resolved?
Intel	NEC	1984	MPU code	Yes
National	Linear Tech.	1985	Analog patents	Yes
International Rectifier	Siliconix	7/86	Patents: MOSFETs	Yes
Motorola	Hitachi	1/89	Patent: MCUs	No
Hitachi	Motorola	1/89	Patent: MCUs	No
Gazelle	AMD	1/89	Patent fraud: PLDs	No
Intel	ULSI System Technology	2/89	Coprocessors	Yes
AMD	Brooktree	5/90	DAC patents	No
Atmel	AMD SEEQ	1/90	Patent: circuitry	No
Chips	Elite Microelectronics	1/90	Trade secrets, breach of contract	No
SGS-Thomson	Dallas Semiconductor	1/90	Patent: battery-backed memories	No
SGS-Thomson	Hyundai	3/90	Patent: memories	No
AMD	Samsung		Patent: PLDs	Yes
Intel	AMD	4/90	Coprocessor code	No

Source: Dataquest (August 1990)

International Trade

The subject of international trade continued to be a hot topic in 1989. The Omnibus Trade Act and the US-Japan Semiconductor Trade Arrangement of 1986 served as the basis for most discussion surrounding international trade. Super 301 is a provision of the 1988 Omnibus Trade Act passed by the US Congress. According to this provision, the US Trade Representative (USTR) must identify "priority countries" and "priority practices" that inhibit US trade in world markets and then take actions against those countries and practices. Many observers, including the SIA, speculated that Japan would be placed on the list of Super 301 offenders for its practices in the semiconductor industry. On May 25, 1989, USTR Carla Hills put an end to speculation about Japan's inclusion on the "Super 301" list for semiconductor trade practices. Although Japan will be investigated under US trade law for committing "priority practices" (i.e., trade barrier erection) in connection with telecommunications satellites and supercomputers, semiconductors will not be a subject of the USTR's investigative focus.

The main focus of the relationship between the United States and Japan relates to the US-Japan Semiconductor Trade arrangement. To date, much of the furor over the implementation of the Arrangement has centered on the issue of measuring market access—and this issue has in turn centered on the interpretation of the now infamous "side letter," dated September 1, 1986, between Ambassador Matsunaga of Japan and Ambassador Yeutter of the United States. One particularly controversial section of the letter reads:

> "The Government of Japan recognizes the US semiconductor industry's expectation that semiconductor sales in Japan of foreign capital-affiliated companies will grow to at least slightly above 20 percent of the Japanese market in five years. The Government of Japan considers that this can be realized and welcomes its realization. The attainment of such an expectation depends on competitive factors, the sales efforts of the foreign capital-affiliated companies, the purchasing efforts of the semiconductor users in Japan, and the efforts of both Governments."

The attainment of 20 percent market share by 1991 has become the de facto measure of Japan's success in opening its markets. In April 1989, Japan's Ministry of International Trade and Industry (MITI) introduced an 11-point, step-by-step plan to solve the US complaint of closed markets. MITI's 11-point plan includes the following provisions:

- MITI will encourage major semiconductor users, including Electronic Industry Association of Japan (EIAJ) users' committee members and Japan Auto Parts Industries Association (JAPIAS) members, to adopt market access plans.
- MITI will encourage expansion of efforts to design-in foreign semiconductors.
- MITI will encourage Japanese manufacturers of consumer electronics to do joint developments with foreign semiconductor suppliers, the objective of which is to increase the foreign semiconductor content in consumer electronics.
- MITI will encourage ISDN equipment makers to aim programs at design-ins of foreign semiconductors.

The success of MITI's efforts thus far is questionable. Andrew Procassini, president of the Semiconductor Industry Associate (SIA), has praised the five largest Japanese semiconductor consumers for increasing their purchases of semiconductors to 17 percent of total supply from foreign suppliers. Dataquest notes that the other Japanese companies procure only about 7 to 8 percent of their semiconductor needs from foreign sources. US and Japan-based market share estimates tend to diverge greatly. In April 1990, the International Semiconductor Cooperation Center (INSEC) announced that a survey conducted to identify the progress of the Japanese market access for foreign-made ICs indicated that the average purchase of foreign-made ICs by 53 users that responded was 12.9 percent. However, Dataquest estimates that foreign ICs accounted for only 10.0 percent of Japanese IC consumption in 1989.

Despite these conflicting claims, we have observed significant effort on the part of some Japanese manufacturers to increase the market share of foreign-made ICs in Japan. In addressing US criticism regarding the inaccessibility of its marketplace, Japan is directing much of its efforts toward responding to this issue through the vehicle of alliances so that greater market access can be achieved via these measures. In March 1989, AT&T and NEC announced an agreement whereby AT&T will obtain a license to design, manufacture, and market NEC's gate array products. Under this agreement, NEC and other Japanese companies will be able to boost their purchases of foreign semiconductors. In another recent agreement, Kobe Steel and TI announced the establishment of a joint venture in Japan to manufacture VLSI ICs and ASICs, which will be sold through TI. In addition, a number of other strategic alliances were formed between US and Japanese companies in 1989. For more details, refer to the subsection entitled "Alliances."

Although most discussion of trade was dominated by US/Japan topics, several developments in Europe also made headlines. In March 1989, the European Economic Community (EEC) announced that it planned to increase the duty rate paid by foreign manufacturers of 256K DRAMs from 10 to 14 percent. The EEC explained that because NEC and Siemens are now producing significant quantities of 256K DRAMs in Europe, the EEC is justified in raising the import duty to the full 14 percent. In February 1990, after months of speculation, the EC announced that an agreement had been reached between itself and the 11 Japanese vendors that sell into Europe. Under the terms of the agreement, a price floor was established for all densities of DRAMs; suppliers cannot legally sell below this floor without facing dumping charges. Although the reference price is not publicly known, it is based on cost, a capital and R&D expenditure allowance, a selling, general, and administrative (SG&A) expense margin and a profit margin of 9.5 percent.

Another European issue that remained at the forefront of international discussions is the scheduled 1992 unification of Europe, with the dropping of inter-Europe trade barriers. Realizing the immense size of a unified European market, many large Japanese and US semiconductor manufacturers continued to invest heavily in European manufacturing facilities in 1989 in order to avoid import duties by producing semiconductors locally.

Alliances

In 1989 and early 1990, a number of strategic alliances were formed between US and Japanese companies. Some of these alliances involved start-ups looking to Japanese vendors for manufacturing capacity for their new products. For example, VIA Technologies has teamed up with Fujitsu to jointly develop chip sets for Sun-compatible workstations. Ramtron signed a joint development agreement with Seiko-Epson under which Seiko-Epson will provide Ramtron with manufacturing capacity for ferroelectric memory products developed jointly with Ramtron. In November, Vitesse signed an agreement with Fujitsu whereby Fujitsu will second-source GaAs ASICs developed by Vitesse. In January 1990, Actel signed a manufacturing agreement with Matsushita that allows Matsushita to manufacture ASIC products for Actel. In February, Echelon formed an alliance with Motorola and Toshiba whereby the two companies will manufacture and distribute semiconductors developed by Echelon. Also in February, Kubota, a Japanese machinery manufacturer, signed an agreement with C-Cube Microsystems to codevelop image-processing ICs.

In addition to these alliances between start-ups and Japanese suppliers, several alliances occurred between major US and Japanese semiconductor manufacturers. In May 1989, Motorola agreed to second-source Toshiba's new 74BC BiCMOS logic family. In July, Hitachi and Texas Instruments agreed to mutually second-source each other's SRAMs. In August, HP licensed its RISC-based Precision Architecture along with its advanced submicron CMOS process technology to Samsung. In January 1990, NMB Semiconductor signed an agreement with Intel whereby NMBS will manufacture DRAMs for sale by Intel. In March, AT&T and NEC announced an agreement under which AT&T will be licensed to design, manufacture, and market NEC's gate array products. In return, NEC will receive AT&T's sophisticated CAD tools for ASICs. The relationship also called for AT&T to provide manufacturing support for NEC's 4-bit microcontrollers.

In recent years, there has been an observable trend among Japanese steel and heavy industry companies toward diversification into the electronics industry. In 1985, Kawasaki Steel formed Nihon Semiconductor, a joint venture with LSI Logic Corporation. In the past year, we have seen two new alliances between Japanese heavy industry companies and US semiconductor companies. One, which was mentioned earlier, is the alliance between Kubota and C-Cube to jointly develop image compression ICs. In March 1990, Kobe Steel of Japan announced a joint venture with Texas Instruments to manufacture VLSI ICs and ASICs. Table 3-4 provides a list of alliances in 1989 and early 1990.

Table 3-4

Alliances: 1989-1990

Company 1	Company 2	Date	ProductType	
Samsung	NCR	January 1989	ASICs, SRAMs	Cross-license
AT&T	Intel	January 1989	Communication ICs	Product & technology exchange
Logic Devices	AT&T	January 1989	SRAMs	Foundry
TI	Acer	February 1989	DRAMs	Joint manufacturing
Fujitsu	VIA Technologies	March 1989	Chip sets	Joint development
Intel	IBM	March 1989	DVI	Joint development
ACC Micro.	Motorola	April 1989	Chip sets	Second-source
Ramtron	Seiko-Epson	April 1989	Ferroelectric memory	Joint development
Sanyo	Mosaid	April 1989	DRAMs	Joint development
Toshiba	Siemens	May 1989	ASICs	Second-source
AMD	Lattice	May 1989	PLDs	Cross-license
Motorola	Toshiba	May 1989	BiCMOS logic	Second-source
Simtek	Plessey	July 1989	EPROMs	Licensing
Hitachi	Goldstar	July 1989	DRAMs	Licensing
Hitachi	TI	July 1989	SRAMs	Joint supply
AMD	ICT	July 1989	EPROMs	Joint development
HP	Samsung	August 1989	RISC	Licensing
AT&T	Paradigm	August 1989	SRAMs	Joint development
SEEQ	Philips-Signetics	October 1989	Flash, EEPROM	Foundry, licensing
Fujitsu	Vitesse	November 1989	GaAs ASICs	Second-source
AT&T	Xilinx	December 1989	ASICs	Manufacturing
Toshiba	Int'l. Rectifier	December 1989	MOSFETs	Licensing
Samsung	Intergraph	December 1989	Clipper MPUs	Licensing
Intel	VLSI	January 1990	Chip sets	Remarketing
National	Acer	January 1990	Micros	Joint development
Intel	NMB	January 1990	DRAMs	Marketing
Siemens	IBM	January 1990	DRAMs	Joint development
Actel	Matsushita	January 1990	ASICs	Manufacturing, marketing
IBM	Siemens	February 1990	DRAMs	Joint development
AT&T	Mitsubishi	February 1990	SRAMs	Manufacturing, marketing, technology sharing
Echelon	Motorola Toshiba	February 1990	LON ICs	Manufacturing
C-Cube	Kubota	February 1990	Image compression	Joint development
AT&T	NEC	March 1990	ASICs, MCUs	Manufacturing, marketing
SGS-Thomson	Siemens	March 1990	MCUs	Second-source
SGS-Thomson	Oki	March 1990	DRAMs	Joint manufacturing
TI	Kobe Steel	March 1990	ASICs	Joint venture
LSI	Hyundai, Metaflow	March 1990	SPARCs	Joint development
Actel	HP	April 1990	ASICs	Joint development
AMD	Vitesse	May 1990	GaAs communication ICs	Joint development
Intel	TSMC	May 1990	DRAMs	Manufacturing

Source: Dataquest (August 1990)

Mergers and Acquisitions

A significant amount of merger and acquisition activity occurred in 1989. An increase in such activity often occurs in periods of industry slowdowns and following periods of extensive start-up activity. Historically, Dataquest has identified a period of consolidation, acquisition, and a shakeout of start-ups following each peak of start-up activity. Although the number of start-ups has recently been declining, the number of mergers, acquisitions, and closures has increased in the last two years. In 1989, four start-ups were acquired by larger companies. Silicon Systems was acquired by TDK; Inmos, the British memory and microprocessor manufacturer, was acquired by SGS-Thomson; Mietec, a Belgian ASIC supplier, was acquired by Alcatel; and Krysalis, a ferroelectric memory start-up, was acquired by National Semiconductor. In addition, LSI Logic merged two of its recent acquisitions, G-2 and Video Seven, to form Headland Technology, a subsidiary of LSI that manufactures PC logic and graphic chip sets.

In addition to these acquisitions of start-ups, a number of other significant acquisitions occurred in 1989 and early 1990. A number of these acquisitions also involved start-ups, as these small companies attempted to gain manufacturing capacity and diversify their product lines. In April 1989, the ASEA Brown Boveri Power Semiconductor Division was acquired by IXYS, a start-up discrete semiconductor manufacturer. In June, the management and employees of Zilog purchased the company from its parent, Exxon, with funding from Warburg, Pincus Capital Company. Also in June, Atmel, a nonvolatile memory start-up, purchased Honeywell's Solid State Electronics division in Colorado Springs, Colorado. Included in the purchase were three wafer fabs plus related assembly, testing, and engineering facilities. General Electric Microelectronics was acquired by Harris in July. In January 1990, Atmel acquired Westinghouse's Chesapeake ASIC design group. In February, Vitelic acquired Elcap Electronics Limited, one of Hong Kong's pioneers in wafer fabrication. In doing so, Vitelic, a start-up memory manufacturer, acquired a 69,000-square-foot wafer fab, which the company will upgrade to a 5-inch submicron production facility.

A list of 1989 and 1990 acquisitions of semiconductor companies is found in Table 3-5.

Semiconductor Megatrends in the 1990s

The following list contains Dataquest's predictions for semiconductor megatrends in the 1990s:

- Economic power will displace military power.
- Closeness to the customer will be an imperative.
- Electronics will pervade all aspects of society.
- Technological obsolescences will increase.
- Consolidation and retrenchment will become the norm.

Table 3-5

Mergers and Acquisitions: 1989-1990

Acquired Company	Acquired By	Date	Product Area
Inmos	SGS-Thomson	March 1989	Transputers, SRAMs, DSP, graphics
G-2	Video Seven*	April 1989	Chip sets
Silicon Systems	TDK	April 1989	ASICs
ABB Power Semi.	IXYS	April 1989	Discretes
Zilog	Employees	June 1989	Microcomponents
Honeywell	Atmel	June 1989	NV memory
GE Micro	Harris	July 1989	ASICs
Krysalis	National	October 1989	NV memory
Mietec	Alcatel	November 1989	Telecom chips
Chesapeake Group	Atmel	January 1990	ASICs
Elcap Electronics	Vitelic	February 1990	Memory

*Now Headland
Source: Dataquest (August 1990)

- Southeast Asia's growth will lead the decade.
- The industry's capital intensity will grow.
- Partnerships will become standard business practice.
- Software will be the king of the '90s.
- Japan will have peaked in growth and the United States will have bottomed out.

Economic Power Will Displace Military Power

We believe that economic power will displace military power as the basis for worldwide dominance. Countries will shift their focus away from military spending and concentrate on strategies to create economic might. Electronic and information transfer industries will be viewed as essential to establishing economic power. Global trade policies will become the new battleground as entities throughout the world seek to protect or enhance their individual economic strengths. Companies that cannot compete on a global basis will realize growth rates and financial returns that are substantially less than industry averages.

Closeness with Customers Will Be an Imperative

Region-based manufacturing should become an imperative of the next decade, as will an entirely new level of service. Driven by trade laws, local content requirements, and the new strategy of establishing factories close to the point of consumption, partnerships such as the Acer/Texas Instruments consortium to produce DRAMs for the Taiwanese market will become commonplace. This fact will hold true for the manufacture of electronic equipment as well as components. Japanese companies already have begun to establish substantial manufacturing capabilities in the United States, and both US and Japanese companies are moving en masse into Europe with IC production factories. Product and price differentiation will be difficult; hence, service will become a new and powerful marketing tool.

Electronics Will Pervade All Aspects of Society

Electronics will become ubiquitous—a common denominator throughout all levels of society. Consumer electronics (with emphasis on personal use) that are perceived to enhance one's life or offer opportunities for saving time will be key drivers during the early portion of the next decade. We see widespread consumption of ISDN-driven products, personal cellular telephones, home fax machines, home copiers and laser printers, and home automation products, as well as personal entertainment systems. This bodes well for analog products as well as for mixed-signal and conventional digital devices. We do not see HDTV as having significant impact on either consumers or IC producers until very late in the decade.

Technological Obsolescences Will Increase

We predict that technological obsolescences will occur at an even faster rate during the '90s than in the '80s. Product life cycles, despite increasing product complexity, will be shorter than in the past decade. Innovation, driven by astounding leaps in software technology and the information transfer industry, will place immense pressures on product survivability. Developing a product that can capture market leadership long enough to recover the investment cost of development will become a key challenge.

Consolidation and Retrenchment Will Become the Norm

The European, US, and Japanese semiconductor industries are expected to reach full maturation in the 1990s. Annual growth rates will more closely follow those of traditional mature industries such as automobiles. Substantial consolidation will take place in the US semiconductor industry, resulting in only a few, very large US semiconductor producers by the end of the decade. Niche market players will become increasingly rare, finding that their markets of choice are too small to allow for annual research and development investments that are commensurate with industry averages. A shakeout will occur among the Japanese device producers as a result of too many participants entering the IC market from nontraditional sourcessuch as the Japanese steel, chemical, and heavy industry companies. The majority of the retrenchments will come from ASIC entities that lack substantial vertical integration capabilities.

Southeast Asian Growth Will Lead the Decade

Southeast Asia will be the region exhibiting the greatest growth and the largest number of new IC ventures. Dataquest predicts that Thailand will become the fifth tiger. Virtually all of the newly industrialized countries (NICs) will adopt the strategy that an indigenous semiconductor industry is essential to the development of a modern economy. The proliferation of ASIC design tools will enhance this region's goal of becoming independent of both Japan and the United States for the supply of complex ICs. India will become an important electronic equipment consumer and semiconductor device producer. The Eastern Bloc and Soviet countries will become significant electronic equipment consumers toward the end of the decade as they realize the necessity of establishing economic rather than military power. China will be neither a significant consumer nor producer of semiconductors. Despite current rhetoric that China's modernization program still is top priority, the impact of the June 1989 events in Beijing will most likely continue well into the next decade.

The Industry's Capital Intensity Will Grow

Dataquest foresees that the capital intensity of the industry will grow. Companies no longer will be able to use DRAMs as their sole process drivers. DRAM technology will pace lithography and three-dimensional events (trench capacitors); however, ASIC technology will set the cadence for multiple levels of interconnections, deposited films, and packaging developments. Consequently, broad market participants will have to make significant investments in both DRAM and ASIC technologies. Wafer fabrication facilities will become product-focused rather than process-focused. Operations will be built principally for the lifetime of one specific product (e.g., factories for 16Mb, 64Mb, and 256Mb products), with possible later-stage revamping for less demanding technologies. This scenario favors commodity memory producers over ASIC and analog producers for the greatest leverage of wafer fabrication capital investment.

Partnerships Will Become Standard Business Practice

Partnerships and technology transfer are likely to become key strategies in the next decade. The staggering cost of technology will be only a portion of the problem to be solved. As product lifetimes decrease, the time to market for products will become predominant. Even a minor setback in product development could translate to missing an entire product cycle, recovery from which may be impossible. Partners not only will share the cost of the technology but also the task of getting the product to market in time to minimize the risk of lost opportunity. The NICs will look to the established countries for technology. This know-how will be exchanged for local market access and assistance in establishing regional manufacturing capability. Companies that lack partnering skills or cannot leverage their technology will suffer against their more adept global competitors.

Software Will Be the King of the '90s

As software standards become pervasive, hardware will become a commodity item. We predict that the Silicon Valley will realize an era of venture capital-backed software start-up companies that will rival the IC company start-up era of the '70s.

Japan Will Have Peaked in Growth; the United States Will Have Bottomed Out

Dataquest anticipates that Japan's amazing growth rate will peak very early in the decade. As the Japanese accept their position as the most wealthy people on earth, they will begin to enjoy the fruits of their efforts and lessen their obsession with economic survival. The younger Japanese generation, having never known the hardships of their elders, will be unwilling to make the same sacrifices of unquestioned long work hours, blind devotion to corporate goals, and lack of personal identity. This phenomenon is not unique to the Japanese, but rather a continuing enactment of the drama that has occurred in every highly successful emerging nation including Ming China, the Ottoman Empire, the countries of Western Europe, Great Britain, and the United States. The United States has bottomed out in its descent and now is finally addressing the decline in global competitiveness, deteriorating industries, poor product quality, the drug problem, and the seeming inability to create products that its citizens will buy. We believe that by the end of the century, Japan and the United States will be virtually at parity; however, Japan still will be slightly in the lead. Both nations will have shouldered many of the world's problems and will unite in their mutual anxiety over the ever-growing economic strength of Southeast Asia.

CHAPTER 4

Electronic Equipment Segment of the Economy

Introduction

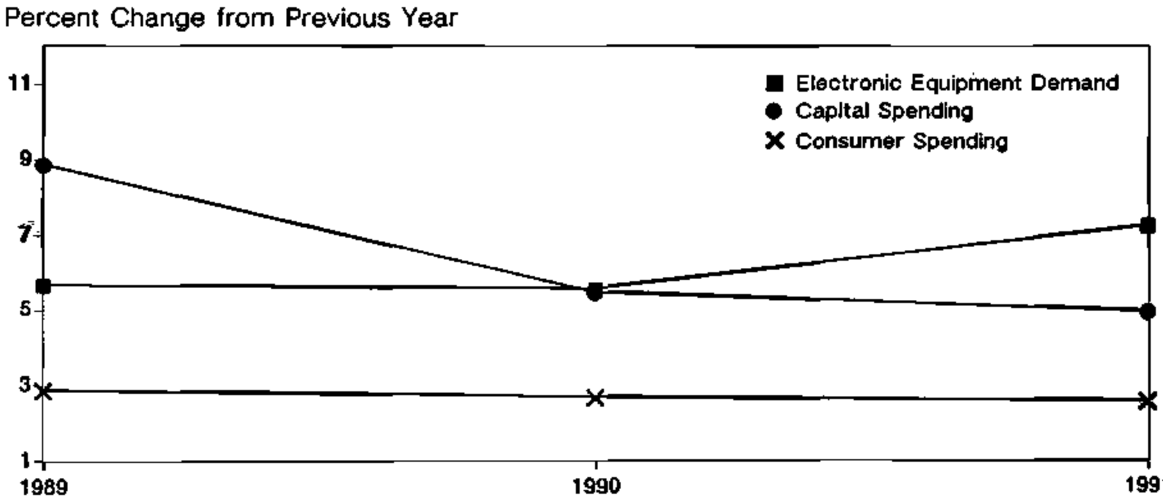
The steadily growing electronic equipment segment of the global economy is a major contributor to worldwide economic growth. Dataquest estimates that 1988 worldwide electronic equipment sales accounted for nearly 8 percent of OECD members' output of goods and services. In 1989, that amounted to $653 billion out of $10 trillion, measured in current US dollars. Illustrative of this growth and contribution is the fact that electronic equipment progressed from less than 3 percent of the OECD output in the mid-1970s to just shy of 5 percent in 1984 to nearly 8 percent in 1988.

Chapter 3 developed the headwaters of the waterfall of demand and established that the global economy has been expanding vigorously since 1987. The major force behind this recent worldwide economic expansion has been spending related to private, fixed, nonresidential investments (capital spending by businesses), as shown in Figure 4-1.

Although worldwide consumer spending has declined considerably as an economic driving force from its 1985 historic levels of more than 5 percent annual growth, it has been on the rise in some regions during the past two years. This increase has occurred in countries that have enjoyed recent buoyant economic growth—Japan, Asian NICs, the United Kingdom, and West Germany. Although Japanese and Asia/ROW consumer spending has been less than that of the United Kingdom or West Germany, it has not been an insignificant contributor to worldwide electronic equipment growth, as shown in Figure 4-1.

Figure 4-1

Worldwide Electronic Equipment Demand versus Capital and Consumer Spending 1989-1991 Annual Growth



Source: Dataquest (August 1990)

Because the electronic equipment industry sells products in all three economic sectors—private business, consumer, and government—the industry has been able to take advantage of the growth in consumer and capital spending. It therefore has enjoyed moderate growth worldwide over the last two years. Dataquest estimates that annual growth for electronic equipment exceeded 16 percent in 1988, whereas 1989 growth was substantial but slower—approximately 6 percent (see Figure 4-1).

This chapter takes the first step down the waterfall of demand. In the process, it develops the following three important topics:

- Demand for electronic equipment—This includes a discussion of worldwide and regional economic demand drivers.
- Production of electronic equipment—Key regional economic and competitive issues discussed in Chapter 3 are used to relate worldwide demand to worldwide and regional forecasts of electronic equipment production.
- Procurement of semiconductor devices—Regional electronic equipment production forecasts are used to generate regional forecasts of semiconductor expenditures for 1989 and 1990. This is addressed as a strategic issue within the section entitled "Electronic Equipment Production."

Electronic Equipment Demand

This section on electronic equipment demand provides the following information:

- Background for electronic equipment demand
- Electronic equipment demand forecast for 1990 and 1991
- Strategic issues regarding the electronic equipment demand forecast

Background

The background information for electronic equipment demand explores the following areas:

- Equipment market segments—What is included in the electronic equipment market?
- Market segment growth—What is driving equipment market growth?
- Sources of demand—Who buys electronic equipment?
- Regional equipment demand—Where is electronic equipment purchased?

Equipment Market Segments

Dataquest segments the electronics industry into six major application markets, defined as follows:

- Data processing
- Consumer
- Industrial
- Communications
- Military
- Transportation

Data Processing

Data processing comprises all equipment that functions as information processors, including all personal computers, regardless of price or the environment in which they are used. About 10 percent of this segment's equipment is assumed to be purchased by the consumer sector of the economy. The balance (90 percent) is purchased by the private business and government sectors.

Consumer

The consumer segment comprises equipment that is used primarily in the home for personal use, such as audio and video equipment and household appliances. All equipment in this segment is purchased by the consumer sector of the economy.

Industrial

The industrial segment consists of all manufacturing-related equipment, including scientific, medical, and dedicated systems. It is assumed that all equipment in this segment is purchased by the capital spending sector of the economy.

Communications

Most of the communications segment is made up of telecommunications equipment, which Dataquest classifies as customer-premises and public telecommunications equipment, and all other communications equipment, such as radio transmission, studio, and broadcast equipment. All of the equipment in this sector is assumed to be purchased by either the capital spending or government purchasing sectors of the economy.

Military

Military equipment is primarily defense-oriented electronic equipment and thus does not include all electronic equipment procured by the government. In order to avoid double-counting, equipment that belongs in an already defined application market segment is not included here. All equipment in this segment is purchased by the government (defense) spending sector of the economy.

Transportation

Transportation consists mainly of automotive and light-truck electronics. All equipment in this segment is assumed to be purchased by the consumer sector of the economy.

Market Segment Growth

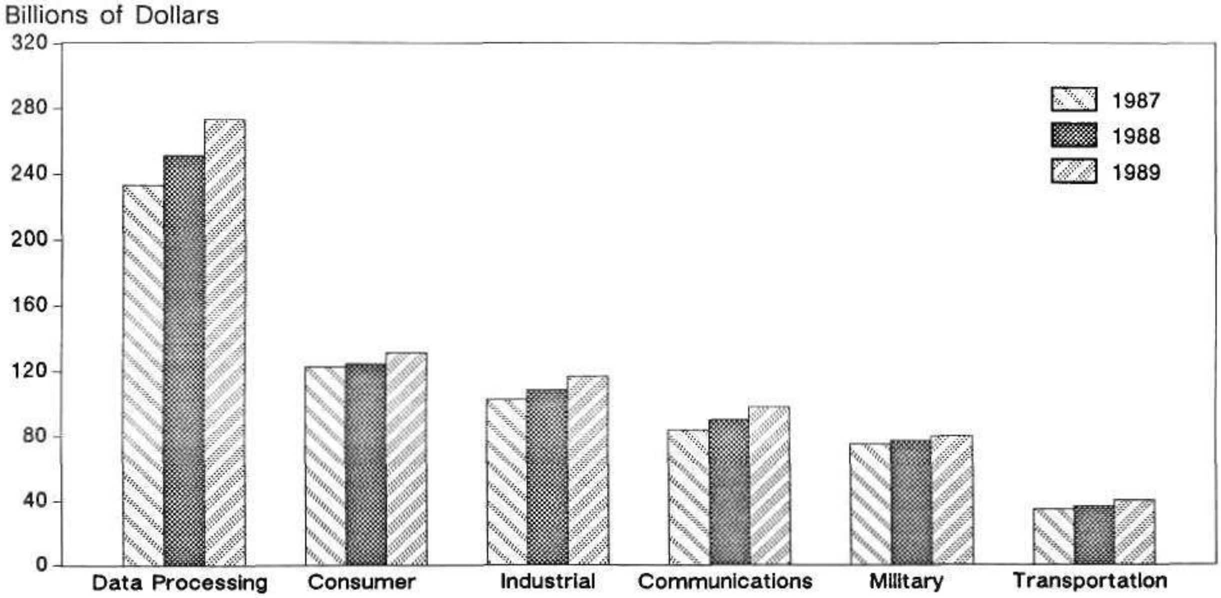
The worldwide electronics industry production growth by application market is illustrated in Figure 4-2. Growth was driven primarily by the data processing and consumer markets. Figure 4-3 shows that although production share of these two segments grew onlyt slightly from 54.0 percent to 54.5 percent from 1987 to 1989, these two market segments still represent a majority of worldwide equipment production and semiconductor demand. At the same time, production share of the industrial market has grown from 14.2 to 15.8 percent over that same period, while the production share for the military segment has dropped from 13.7 percent to 11.6 percent.

Major growth products within the data processing and consumer markets have been personal computers, workstations, storage peripherals, terminals, personal printers, VCRs, and compact disc players. These growth products have the following common attributes:

- High semiconductor content
- High unit volume
- Large market (All of these products are used by individuals and thus are assured of a large total available market.)

Figure 4-2

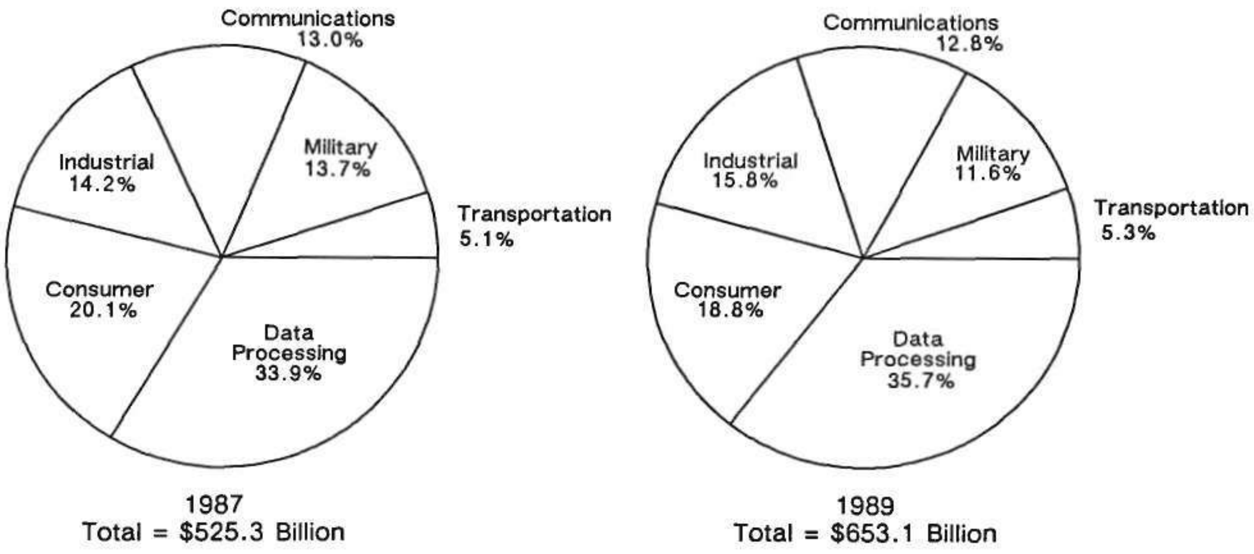
Worldwide Electronic Equipment Market Growth by Application Market Segment—1987-1989



Source: Dataquest (August 1990)

Figure 4-3

Worldwide Electronic Equipment Production Share
by Application Market Segment—1987 and 1989



Source: Dataquest (August 1990)

Demand Sources

The growth in worldwide demand for electronic equipment is determined by the growth in worldwide spending from the following three major economic sectors:

- Private, fixed, nonresidential investments (otherwise known as capital spending)
- Consumer spending
- Government spending

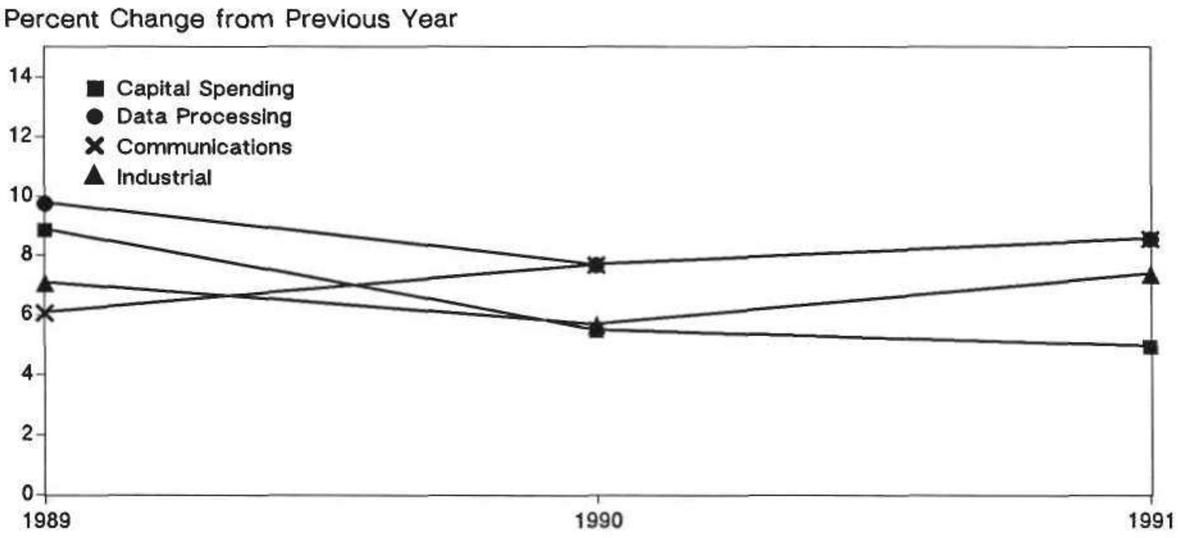
It is important to note that, in terms of demand growth, individual market segment growth is a function of the growth of the economic sectors in which major purchases occur. For example, the data processing, industrial, and communications segments are purchased mostly by the capital spending sector and represent nearly 60 percent of total equipment demand. The consumer and transportation segments are purchased mostly by the consumer sector and represent approximately 30 percent of total demand. All of the military segment is purchased by public sector and represents 10 percent of the total equipment demand. Supply issues, on the other hand, tend to be more global in nature. The growth of the equipment demand as a whole therefore is determined by the growth rates of the individual economic sectors weighted by the relative size of each sector, as well as supply-side issues such as price and technology.

Additionally, it is important to note that small percentage changes in sector spending can have a big impact on equipment demand due to the size of the consumer spending sector. Any change in capital spending has a direct and significant impact on equipment demand, particularly in the data processing, communications, or industrial segments (see Figure 4-4). Furthermore, as Figure 4-5 shows, consumer and transportation segments are tied to the consumer spending sector. The consumer spending sector has been flat and is forecast to continue the same pattern, but the consumer equipment and transportation segments have experienced dynamic growth swings resulting from relatively small changes in consumer spending.

As a historical example of how economic sector spending influences electronic equipment demand, consider the 1985 and 1986 near-recession in the United States. Through 1983 and 1984, the US economy was enjoying a consumer-driven shopping spree. This spree stimulated North American capital spending, as companies in all segments of the economy scrambled to increase capacity and productivity to participate in the boom. The high value of the dollar drove import prices well below those of domestic products, and Japan, the Asia/ROW countries, and West Germany were the major benefactors from all this spending. Figure 4-6 illustrates actual and forecast worldwide and regional consumer spending growth rates for the 1986 to 1991 period.

Figure 4-4

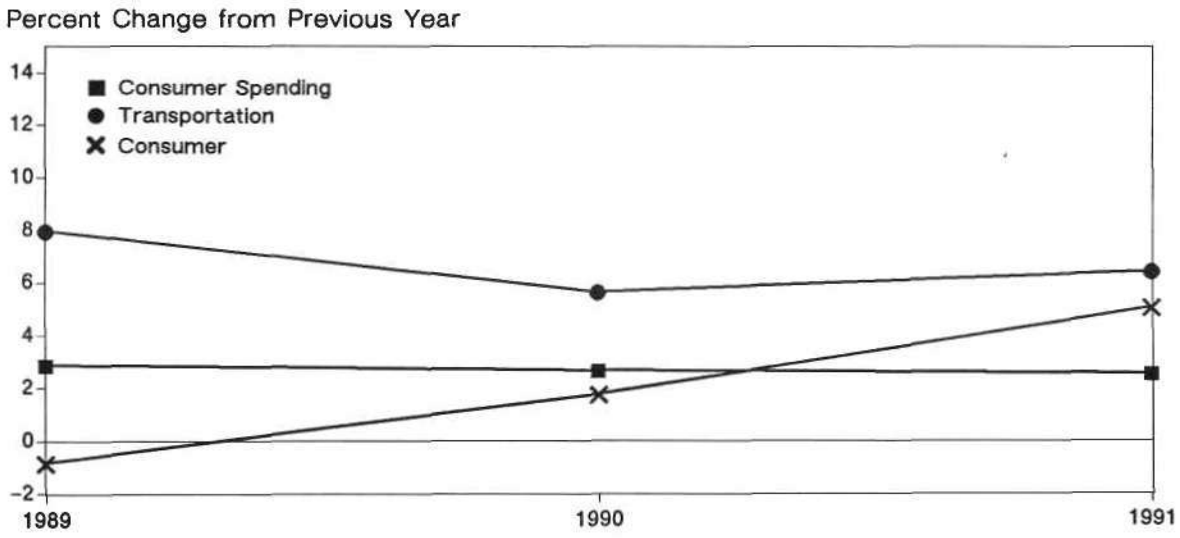
Worldwide Electronic Equipment Demand and Capital Spending by Application Market—1989-1991



Source: Dataquest (August 1990)

Figure 4-5

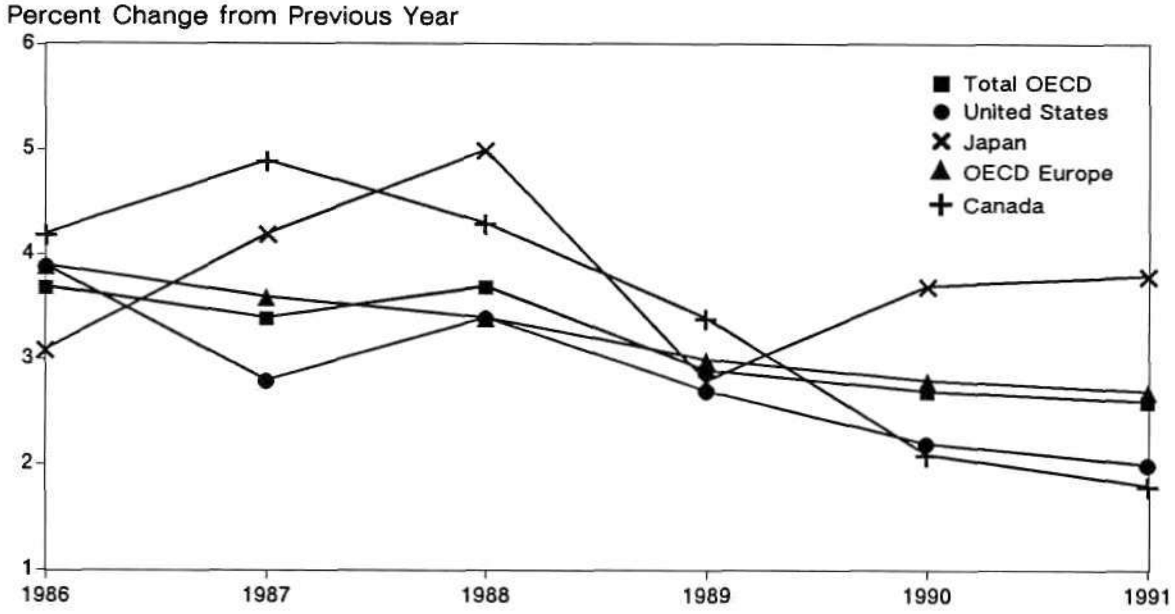
Worldwide Electronic Equipment Demand by Application Market—1989-1991



Source: Dataquest (August 1990)

Figure 4-6

Actual and Forecast Worldwide and Regional Consumer Spending—1986-1991



Source: Dataquest (August 1990)

By 1985, the strength of the dollar had all but choked US exports. Rapidly rising interest rates that were due to the high demand for funds to finance all the deficit spending stalled capital spending growth as well.

However, from 1986 through mid-1989, North American equipment demand was buoyant, aided by increasing growth rates of North American capital spending (see Figure 4-7). Growth in electronic equipment demand is expected to be moderate through 1991, as the worldwide economy remains relatively soft. US capital spending fell 3.3 percent in 1986 before rebounding 3.9 percent in 1987 and 8.4 percent in 1988, which is shown in Figure 4-7.

Regional Equipment Demand

The regional equipment demand forecasts provided are based on the following assumptions:

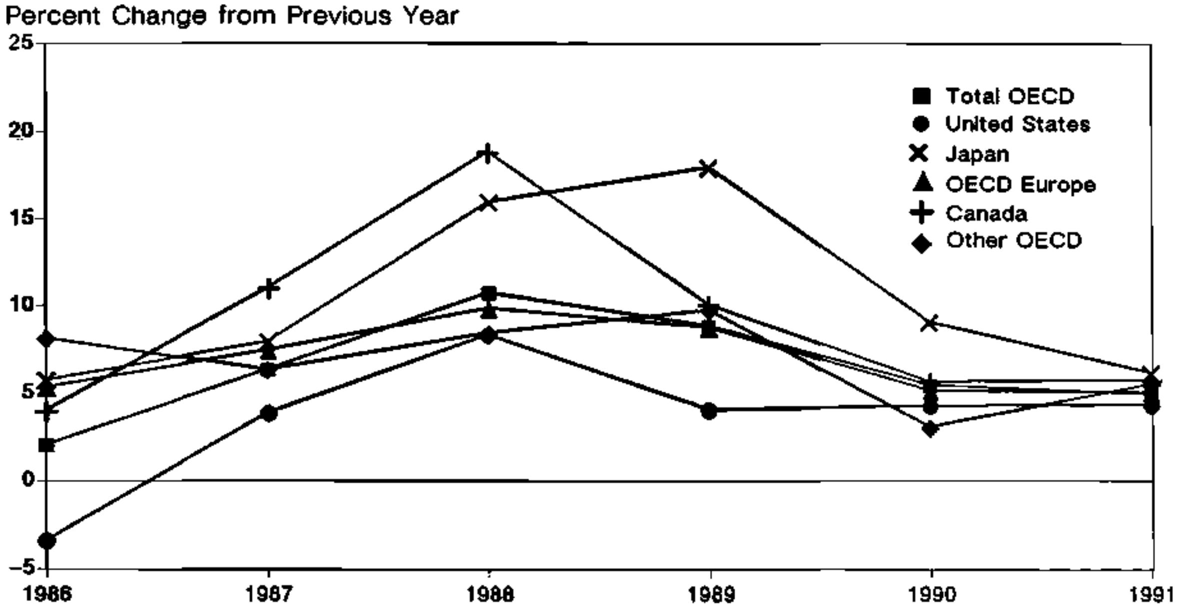
- Individual market segment growth is a function of the economic sector in which the major purchases occur.
- Small changes in sector spending can have a large impact on equipment demand.
- Regional annual growth rates of electronic equipment demand are determined by the weighted average of the annual growth rates of consumer and capital spending within each region.
- Each region's share of electronic equipment demand is approximately equal to its share of worldwide capital spending.

Over the past five years, the share of electronic equipment demand has shifted from the United States and Europe to Japan and the Asia/ROW nations. The fundamental reasons for this shift in regional demand are as follows:

- Japan and the Asian NICs were the major suppliers to the US import shopping spree from the 1983 through 1985 period. As a result, at different times throughout the period, they all experienced heavy capital spending growth to expand production capacity, productivity, and competitiveness. This resulted in increased demand for electronic equipment (data processing, industrial automation, and communications). Figure 4-7 shows that Japanese capital spending remained strong through the 1985 downturn in the United States, as did that of the Asia/ROW region.

Figure 4-7

Worldwide and Regional Capital Spending—1986-1991



Source: Dataquest (August 1990)

- Since 1987, as the benefits of this Japanese and Asian expansion have been realized in terms of increased disposable incomes, consumer spending in these countries has surged (see Figure 4-7).

Electronic Equipment Demand Forecast—1990 and 1991

Forecasts by economists at The Dun & Bradstreet Corporation suggest a considerable slowing of worldwide capital spending through 1991. As shown in Figure 4-8, capital spending is forecast to slow from nearly 9 percent in 1989 to approximately 5 percent in 1991.

The impact that this slowdown is expected to have is that growth in demand for electronic equipment will also drop slightly, from 5.7 percent in 1989 to 5.6 percent in 1990, followed by an increase in the growth rate to 7.3 percent.

The 1989 through 1991 worldwide demand forecast by application market is given in Figure 4-9. This is based on Dataquest's forecast, which is shown in comparison to the OECD worldwide capital and consumer spending forecast in Figures 4-6 and 4-7.

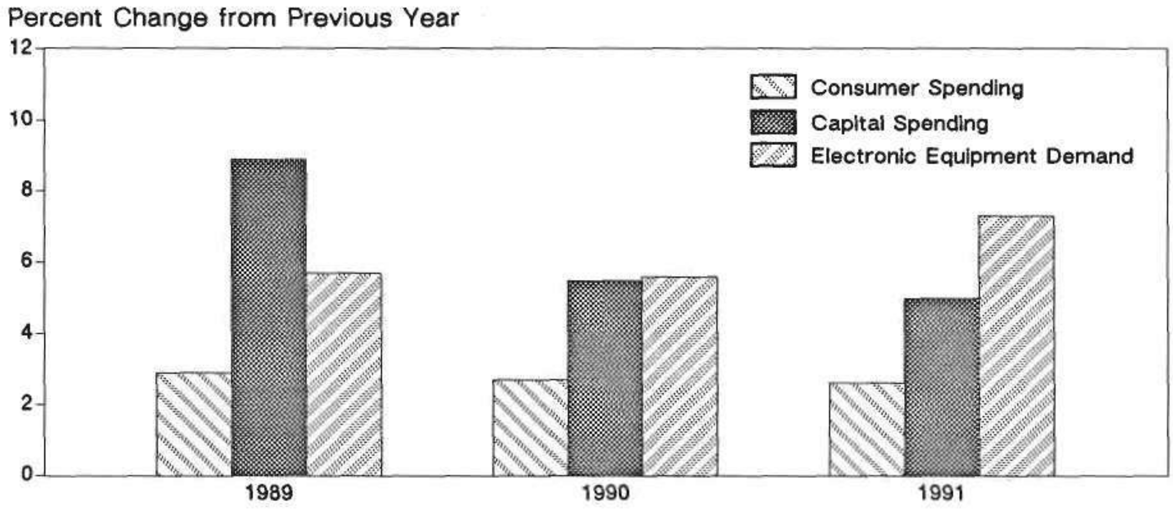
Two Strategic Issues Regarding the Demand Forecast

What Is the Regional Economic Impact on Electronic Equipment?

North America. The annual growth of the real US GNP (adjusted for inflation) is expected to increase during the second half of 1990, reaching an annualized rate of 4.0 percent by the fourth quarter. The first quarter of 1991 is expected to show slower growth in GNP at 3.8 percent. The GNP growth rate is forecast to decline throughout 1991, reaching a rate of 2.8 percent by the fourth quarter. For the year 1991, US GNP growth is expected to be 3.4 percent. The capital spending forecast follows GNP growth closely. A strong second half of 1990 is expected to lift growth rates of capital spending over those of 1989. Growth in capital spending in 1990 is expected to be at 4.0 percent, up from 3.5 percent in 1989. In 1991, despite a slight decline in growth throughout the year, capital spending is expected to grow at 7.1 percent. As a result, the growth of North American demand for electronic equipment is expected to increase modestly beginning in the second half of 1990 and continuing through 1991.

Figure 4-8

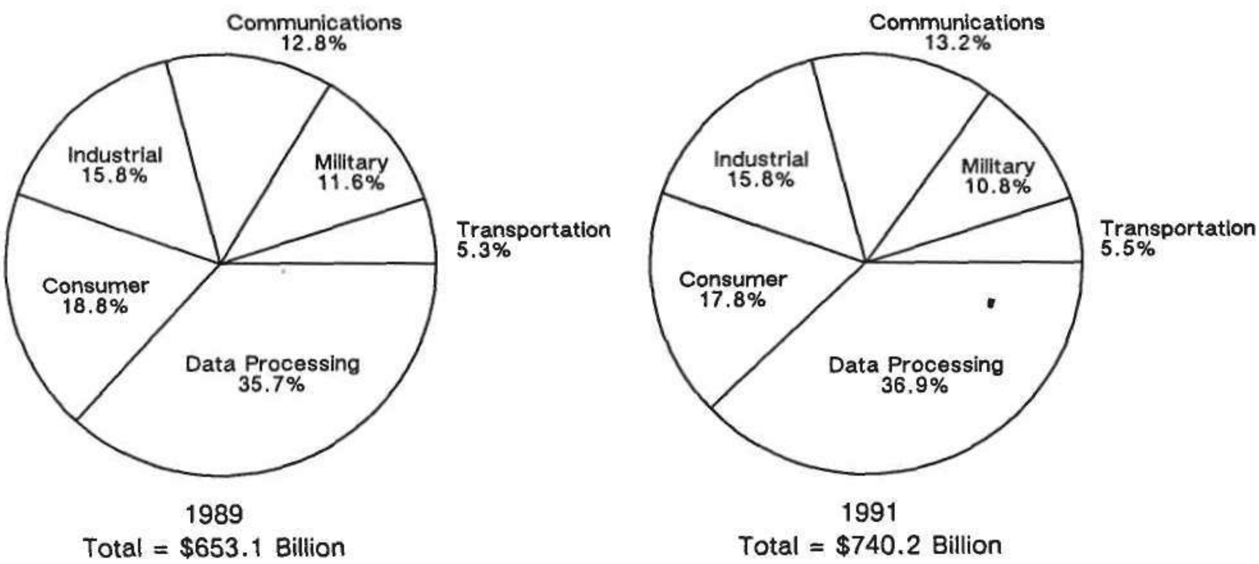
Worldwide Electronic Equipment Demand and Consumer and Capital Spending Annual Growth—1989-1991



Source: Dataquest (August 1990)

Figure 4-9

Worldwide Electronic Equipment Demand Share Estimate and Forecast by Application Market Share—1989 and 1991



Source: Dataquest (August 1990)

Europe. The European electronic equipment demand is forecast to grow at a decreasing annual rate through 1991. Again, this is a result of the forecast slowing of real GNP/GDP growth and its amplified impact on capital spending throughout Europe. The European countries will avoid feeling the full slowdown that is affecting the United States, largely because of the widespread capital spending by both European and Pacific Rim countries in preparation for the EEC market consolidation in 1992.

Japan and Asia/ROW. Because the capital and consumer spending growth of Japan and the Asian NICs is not expected to fall as sharply as that of the North American and European regions, the electronic equipment demand compound annual growth rate (CAGR) in these regions remains higher than in that of the other regions. The continued investment by Japanese electronics companies in offshore production will continue to stimulate demand growth in the Asian NICs. The demand share for electronic equipment therefore will continue to shift toward Asia and Japan.

What Are the Major Demand Drivers?

The application market forecast to show the highest growth still is data processing, followed by the communications and industrial segments. This is a result of the continued expansion and modernization in the Asian NICs and Japan. Modernization and productivity improvement in process in Europe also will contribute to the growth of these segments.

The slower growth of the consumer and transportation segments reflects the forecast decline in consumer spending within the regions with the largest populations—North America and Europe.

The US fiscal restraint evident in the 1989 and 1990 federal defense spending budget has caused the slower growth forecast in the military segment.

Electronic Products—Largest Demand Drivers. Within those market segments showing the most demand growth, the specific products that are driving this growth are shown in Table 4-1. Table 4-2 shows those end products forecast to show the steepest decline.

What are the Factors Affecting the Supply Side?

Although a portion of market growth can be explained by changing preferences and spending patterns, still more of the growth is explained by supply-side factors.

Three major factors affecting the supply of electronic equipment are technology, cost of goods sold, and production costs. As technology improves and costs of raw materials and production decline, manufacturers become willing to supply a greater number of finished goods at the same selling price. In economic terms, this translates into a rightward shift in the market supply curve, which leads to a lower market price and a larger quantity of goods sold.

Table 4-1

Growing North American Application Markets—1989-1993
(Millions of Dollars)

	1989	1990	1993	CAGR 1989-1993
Optical Disk Drives	120	222	1,360	83.5%
3- to 4-Inch Rigid Disk Drives	2,990	4,209	7,195	24.5%
Workstations	5,398	7,160	13,222	25.1%
LANs	3,774	4,959	7,857	20.1%
Voice Messaging Systems	675	825	926	8.2%
Total	12,957	17,375	30,560	23.9%

Source: Dataquest (August 1990)

Table 4-2

Declining North American Application Markets—1989-1993
(Millions of Dollars)

	1989	1990	1993	CAGR 1989-1993
5.25-Inch Flexible Disk Drives	3,192	3,146	2,608	(4.9%)
Alphanumeric Display Terminals	1,668	1,220	442	(283.0%)
Modems	1,237	1,139	795	(10.5%)
Line Printers	1,614	1,561	1,354	(4.3%)
Electronic Typewriters	935	849	575	(11.4%)
Total	8,646	7,915	5,774	(9.6%)

Source: Dataquest (August 1990)

Electronic Equipment Production

Electronic equipment production directly determines the demand for semiconductors. The success and growth of electronic equipment producers within a given region determines the size and growth of the total available market for semiconductors within that region.

The success and growth of electronic equipment producers depends to a large degree on their products. However, the economic conditions of the region—labor costs, interest and currency exchange rates, and the availability of patient investment capital—play a large role as well. These factors determine productivity and hence competitiveness, thus influencing a company's ability to compete for worldwide demand for its products.

This chapter takes the next step down the demand waterfall shown in Figure 4-10 and relates the worldwide and regional demand for electronic equipment discussed above to the production of electronic equipment and hence to the demand for semiconductors.

Background

Electronic equipment producers build end products by assembling printed circuit boards containing semiconductors, other electromechanical or mechanical devices, and a power supply into a package or container. The manufacturing steps are as follows:

- Fabrication of the individual subassemblies, PC boards, and packaging
- Assembly of all these pieces
- Test and verification that the product works and meets specifications

These manufacturing steps frequently involve the need for labor with good manual skills. Low-cost production translates to low-cost but highly skilled labor and considerable automation of much of the fabrication and testing portions of the process.

During the 1970s, emerging semiconductor technology enabled more and more functionality in smaller and smaller physical packages, and electronic products generally became more of a commodity. Successful producers required very large production volumes to be truly competitive.

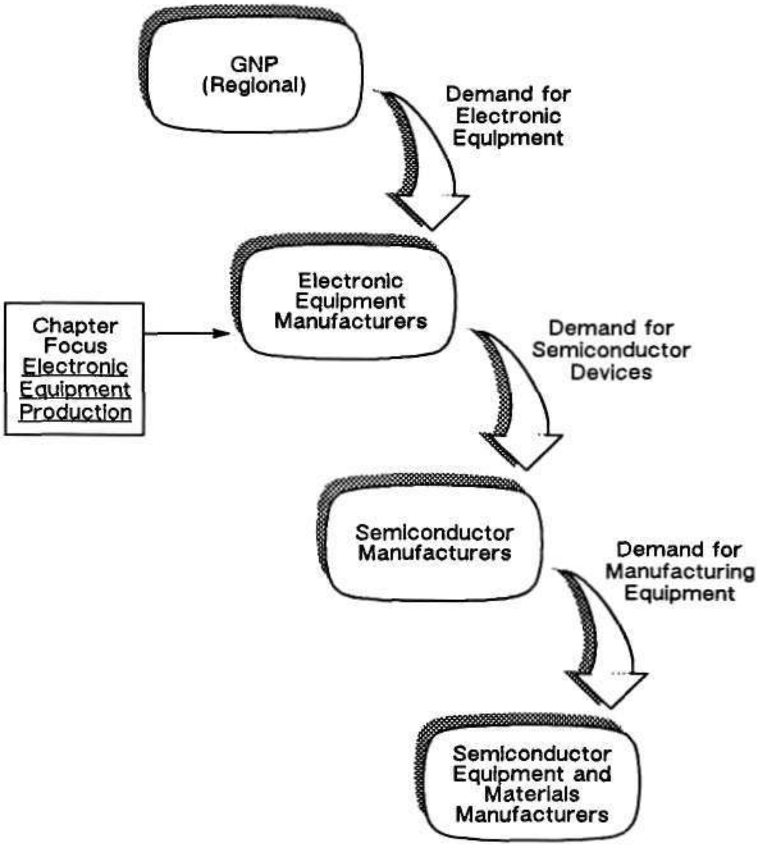
Meanwhile, early in the 1970s, Japan began to execute a multiphased strategy to accomplish a national objective: to become a world-class producer of consumer, communications, and data processing equipment. The execution of this was truly national in scope and involved teamwork between the government, sources of patient capital, and many individual business entities.

The strategy itself embodied the following four steps:

- License the technology or manufacturing rights to a key product
- Leverage Japan's manufacturing and quality assurance ingenuity and highly favorable economic climate, especially the low-cost, dedicated, and skilled labor force, to manufacture the product very cheaply in high volume

Figure 4-10

Waterfall of Demand



Source: Dataquest (August 1990)

- Capture market share in the United States and Europe (and thus generate demand appropriate to the low-cost production volume) through aggressive pricing
- Gain dominance and ownership of the product by adding market-driven proprietary enhancements as experience is accumulated

In response, during the 1970s, US electronics manufacturers began to move their production offshore to Taiwan and other Asian countries whose low-cost, highly skilled labor force and favorable economies ensured competitiveness with Japan.

In many of these countries, companies have evolved that have honed these manufacturing skills to a fine edge because of the huge production volumes they have run through their factories for US companies. These companies have either learned or licensed the requisite product technologies to develop their own products and by now, have leveraged their high-volume production capabilities into formidable competition for their original US customers.

Japan became the premier producer of consumer electronics in the early 1980s to the extent that the United States is all but out of that business now. RCA is an example of an early electronics innovator that no longer is a participant. South Korea became the offshore production site for Japan when Japanese costs rose; now South Korea is the premier producer of consumer electronics. From 1983 through 1985, Taiwan became the offshore production site for numerous US PC clones and add-in boards; now Taiwan is a serious worldwide competitor in all aspects of the PC market. Similar examples exist for computer peripherals, such as disks, printers, terminals, and modems.

Where Is Electronic Equipment Produced Today?

North America is still the dominant producer of data processing, communications, and industrial electronic products, but the trend clearly indicates significant erosion of North American suppliers. When any electronic product, such as computers, communications devices, or industrial products, reach the commodity volume level, the US economy and business climate are not in a good position to compete on an international scale with Japan and the Asian NICs. Therefore, more and more electronic equipment production—particularly high-volume production—will be done in Japan and the Asian NIC regions.

Although this trend has been going on since the 1970s, it accelerated between 1985 and 1986 when the US worldwide production share fell from its 1984 level of 48 percent to 44 percent in 1986. The dramatic shift in power from US suppliers to Japanese and Pacific Rim suppliers began with the 1984 boom market in the United States; it is continuing today. The following three major events occurred during the 1984 through 1989 period:

- The 1985 near-recession
- The application of commodity supply rules by Japanese and Asian suppliers
- US suppliers weakened and reduced

In order to understand where the production is today and appreciate where it will be tomorrow, a review of the 1984 through the 1988 events follows.

1984—A Year of Excessive Demand

All sectors of the US economy were engaged in vigorous buying in 1984; it was a very good year. Capital spending was up 17.7 percent over 1983. Consumer spending was up 4.4 percent, and government spending was up more than 4.5 percent. Demand for all types of products was very high; electronic equipment was no exception. Among electronic products, demand was especially strong for personal computers, work group and small departmental computers, manufacturing systems, and communications systems. Consumer products such as TVs, VCRs, and home appliances were also in high demand.

Also by 1983 and 1984, a crowd of new North American companies emerged, manufacturing communications equipment, personal computers, PC peripherals, and related products. Many producers of such equipment from Japan, Taiwan, and South Korea also were entering the US market during this period.

During 1984, the beneficiaries of the buying spree were both domestic equipment producers and foreign importers. The extremely high dollar plus the indigenous superior productivity of Japanese and Asia/ROW economies made their products very competitive in the United States.

US Equipment Producers Flourish

In spite of their inferior competitiveness, US equipment suppliers still did well because of the very high demand and the "newness" of many of the data processing and communications products. This was especially true of the PC product segment that was experiencing extraordinary demand. Many domestic producers were successfully gaining share of this "hypermarket." US producers of PCs, small microprocessor-based systems, peripherals, and a variety of communications products experienced growth in 1984 ranging from 70 percent for PCs to 20 percent for communications equipment.

Market research forecasts during 1984 were extremely bullish for PCs and communications products. Many US companies geared up for expanded production, and because DRAMs and some microprocessors were in short supply, ordered aggressively.

The Bubble Bursts

The situation was ripe for a fall. This plunge started in early 1985 when US capital spending growth fell off to only 6.7 percent in 1985 (and plummeted to a negative 4.5 percent growth in 1986). A sharp decline in demand for electronic equipment during 1985 and 1986 resulted.

US Loses Numerous Equipment Producers

When US demand fell off, US equipment producers were unable to compensate for the reduced domestic demand by increasing their exports. They found themselves fundamentally unable to compete with Japanese and Asia/Pacific producers. The sharp reduction in US equipment demand also put severe competitive pressure from Japanese and Asian producers on US equipment producers in the US market. (See Chapter 2 for a review of how Japanese and Asia/Pacific suppliers excelled by applying the basic rules of marketing commodity products.)

Many US suppliers, unable to meet competitive pressure in a declining market, went out of business, were acquired by larger suppliers, or were acquired by Japanese, Asian, or European companies. The net result was that by the end of 1986, there were significantly fewer US electronic equipment producers, and the foreign producers were all that much stronger.

Thus, because of their fundamental superior competitiveness, the Japanese and Asia/ROW producers were less affected by the US equipment demand decline. Not only were they effectively able to balance the reduced US demand with sales to other markets, but they also increased their share of the declining US market.

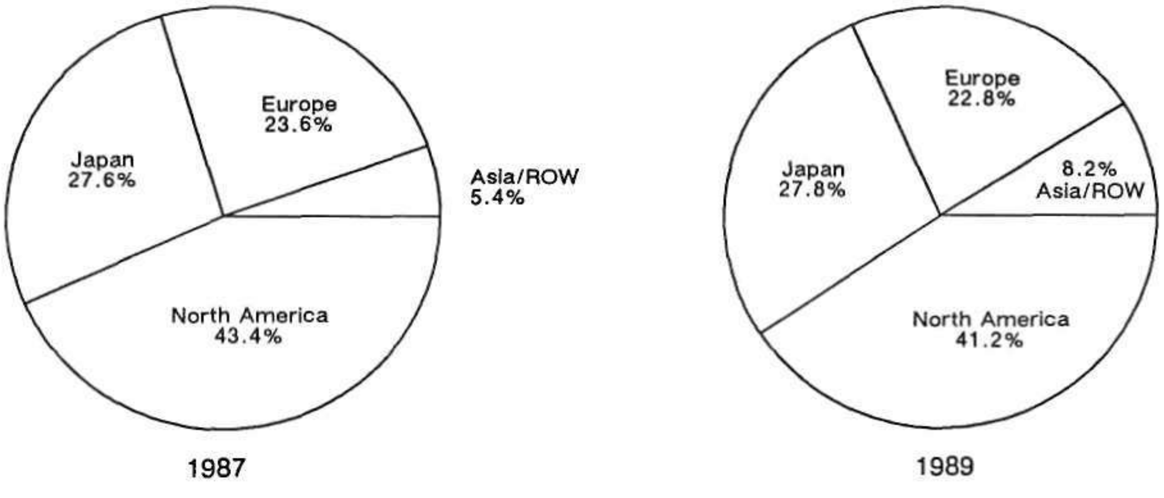
By mid-1987, the US dollar, interest rates, and prices had fallen to the extent that the United States was extremely competitive. At that time, the United States commenced an export effort that has stimulated the US economy in concert with all other regional economies. Worldwide capital spending and equipment demand surged. The result was the extraordinary recovery of electronic equipment production from 1985's low point through mid-1989. Since that time, equipment production growth has slowed as the growth of worldwide capital spending slowed.

During this dynamic recovery period leading up to 1989, the replacement by foreign suppliers of the equipment producers shaken out by the 1985 recession and the offshore move by many US producers contributed to a continuing but more gradual shift in electronic equipment production to Japan and the Asia/ROW countries.

Figure 4-11 illustrates this production shift from North America to Japan and the Asian NICs. The North American share of electronic equipment production declined from 43.4 percent in 1987 to 41.2 percent in 1989, while Japanese and Asia/ROW share climbed to 36.0 percent in 1989. Taken separately, the production share for the Asia/ROW region increased from 5.4 percent in 1987 to 8.2 percent in 1989. European share of worldwide electronic production dropped from 23.6 percent in 1984 to 22.8 percent in 1989.

Figure 4-11

Regional Shares of Worldwide Electronics Production—1987 and 1989



Source: Dataquest (August 1990)

Electronic Equipment Production Forecast—1990 and 1991

The 1990 and 1991 Dataquest forecast for electronic equipment production is presented in Figures 4-12 through 4-17.

Three Strategic Issues Regarding Equipment Production

What Regional Production Shifts Will Occur During the Forecast Period?

North America. Dataquest forecasts that North American production will increase 5.8 percent in 1990 to $285 billion, down slightly from the 6.0 percent growth of 1989. The negative impact of the capital spending forecast is not expected to be as dramatic for production as for demand because of continued exports to Europe of computer, industrial, and communications products.

Dataquest predicts reasonable growth for the 1989 to 1991 period in each of the six application market segments, except military and consumer, with CAGRs in excess of 6.5 percent in each of the four remaining segments (see Table 4-3). PCs and workstations will drive the data processing segment growth: local area networks (LANs) are expected to drive the communications segment. The US LAN market alone is forecast to grow approximately 33 percent to about $5.5 billion in 1990.

Europe. The 1992 effect is the preparation by European, Japanese, South Korean, and some US companies for the single European market of 1992. Real GNP growth in the EEC is expected to fall from 3.6 percent in 1989 to 2.9 percent in 1990 and finally 2.8 percent in 1991. Data processing, communications, and consumer product manufacturing will strengthen as companies, both foreign and domestic, build production facilities within the EEC. Only the data processing and transportation market segments will maintain double-digit growth rates throughout the period.

Japan. The Japanese economy continues to achieve strong growth rates. These rates are, however, expected to decline slightly over the next two years. After a real GNP growth rate of 4.8 percent in 1989, the growth rates are expected to decline to 4.5 percent and 4.3 percent in 1990 and 1991, respectively. Recently, we have seen a devaluation of the yen. The likely effect of this relatively weaker yen is higher exports and lower imports. Japanese electronic equipment production is not forecast to grow as rapidly as strong domestic demand. As Japan continues to contract equipment production to other Asian countries, it is expected that its share of worldwide production will fall slightly.

Asia/ROW. Asia/ROW electronic production should be the fastest-growing of all four major regions through the forecast period, partly because Japan and the United States have been shifting production to this region. This growth also is driven by consumer products, PC clones, and related products. Asia/ROW consumer production is forecast to increase 13.9 percent in 1990; data processing should increase 14.2 percent. The Asia/ROW telecommunications segment is growing rapidly, but to date it is still a relatively small share of total production.

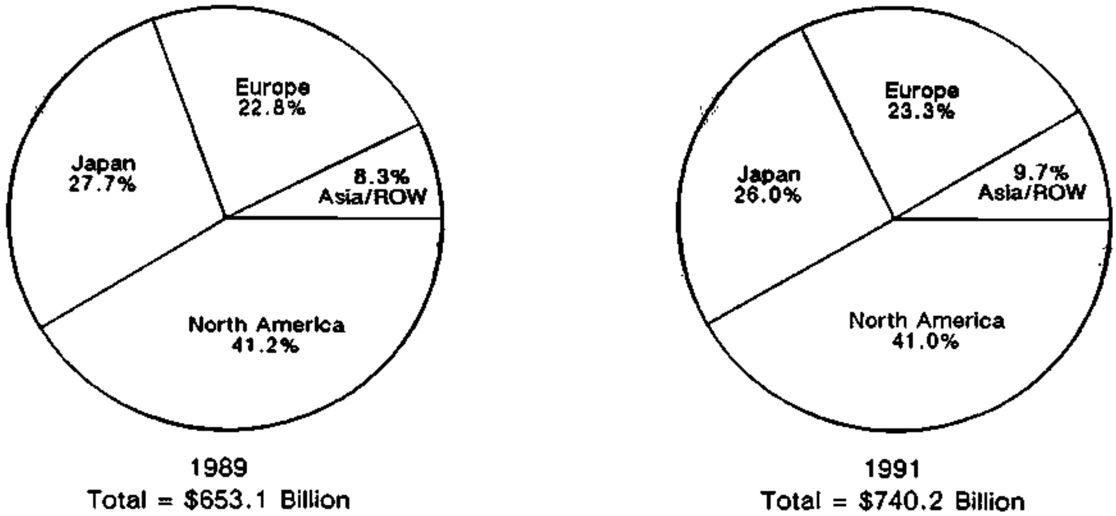
The consumer product segment is expected to undergo such dramatic growth because of the huge potential demand from regions just beginning to open their markets to consumer product imports. Vast markets such as China and Thailand represent massive potential to Asia/ROW producers as well as to Japan-based companies that have built production facilities in this region.

What Will Each Region Spend on Semiconductors?

Table 4-4 shows the semiconductor demand and forecast by region. The worldwide projections for semiconductor demand (expenditures), also shown in Table 4-4, are expected to grow throughout 1990, although 1990 is forecast to be a year of negative growth compared with 1989. Overall 1990 semiconductor demand is expected to decline by 1 percent in 1990, followed by a growth rate of 17 percent in 1991. The merchant market is expected to reach $60.9 billion in 1990 and to grow to $65.6 billion in 1991.

Figure 4-12

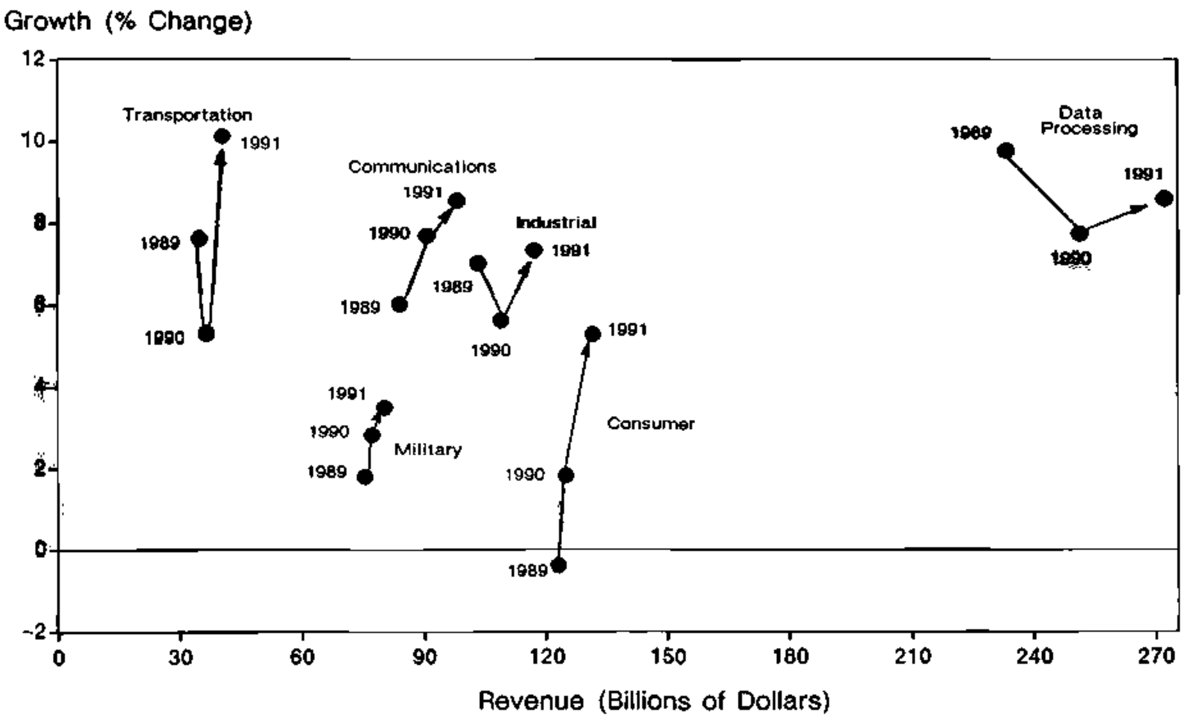
Regional Shares of Worldwide Electronic Equipment Production—1989-1991



Source: Dataquest (August 1990)

Figure 4-13

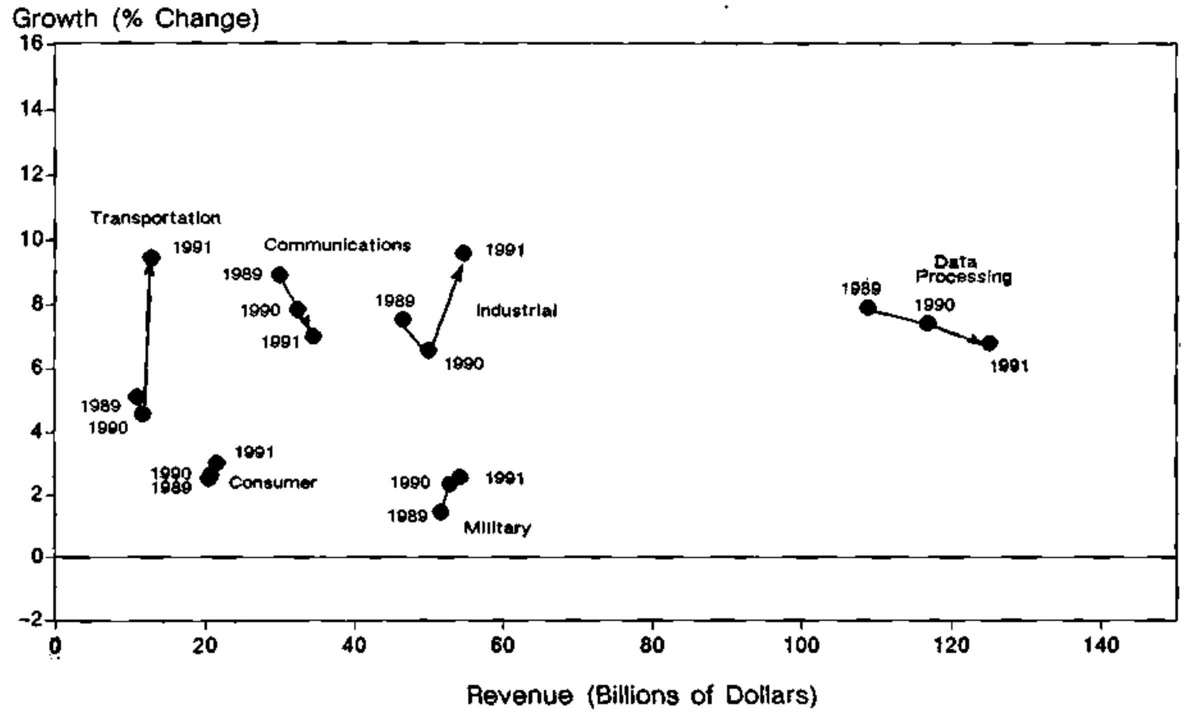
Growth Trends for Application Segments—Worldwide



Source: Dataquest (August 1990)

Figure 4-14

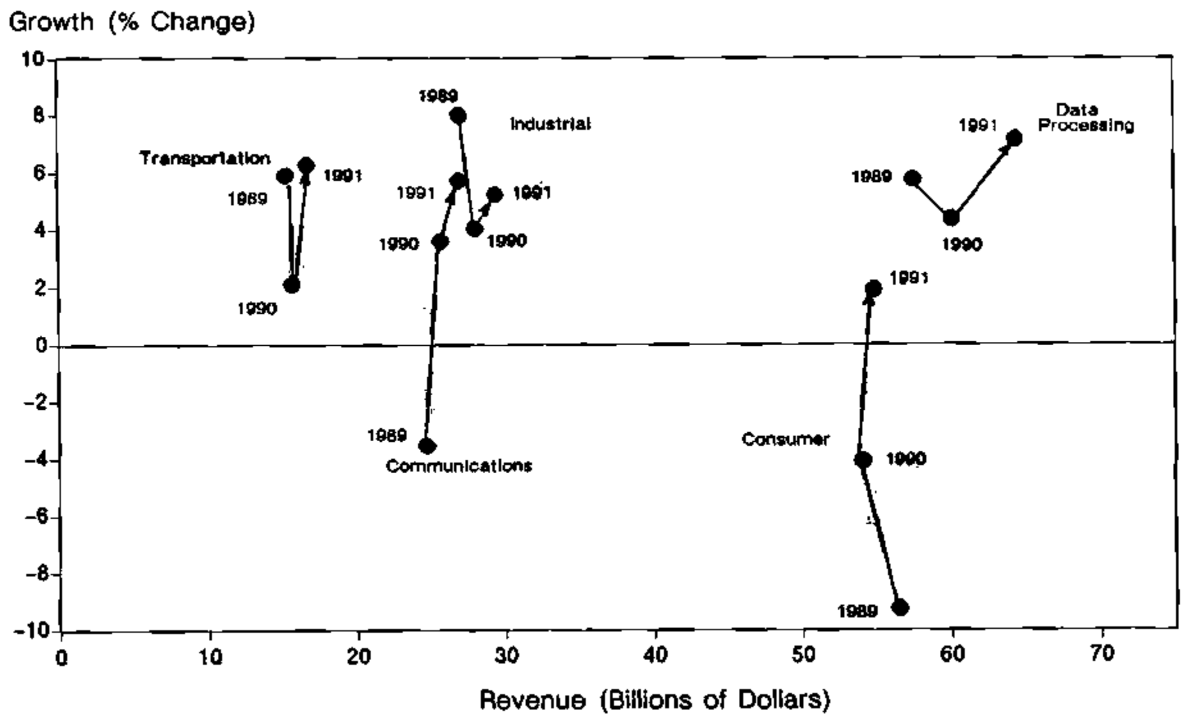
Growth Trends for Application Segments—North America



Source: Dataquest (August 1990)

Figure 4-15

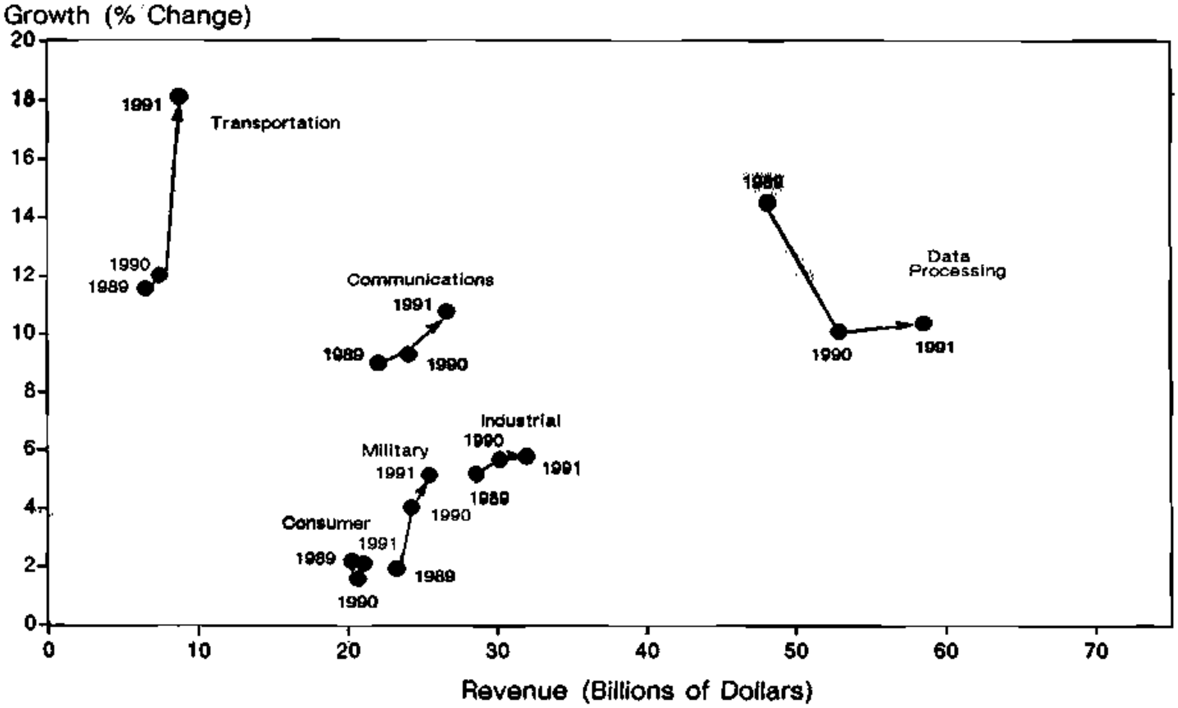
Growth Trends for Application Segments—Japan



Source: Dataquest (August 1990)

Figure 4-16

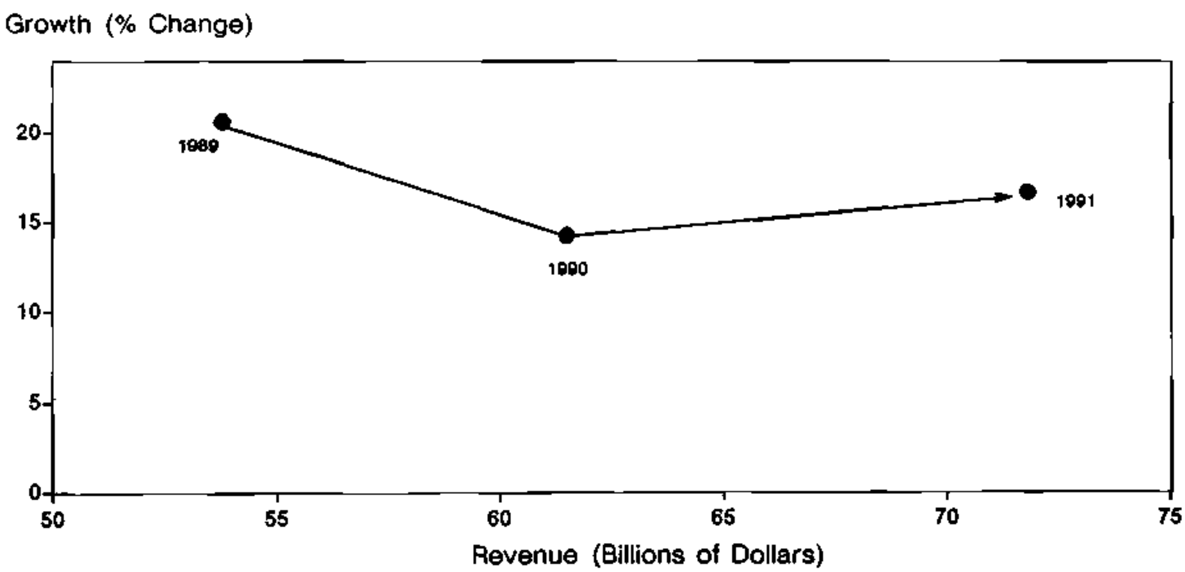
Growth Trends for Application Segments—Europe



Source: Dataquest (August 1990)

Figure 4-17

Electronic Equipment Growth Trends—Asia/ROW



Source: Dataquest (August 1990)

Table 4-3

North American Electronic Equipment Production History and Forecast—1989-1991 (Millions of Dollars)

Segment	1989	1990	1991	CAGR 1989-1991
Data Processing				
Computers	74,757	80,892	88,073	8.5%
Data Storage Subsystems	17,998	19,736	20,254	6.1%
Data Terminals	2,584	2,081	1,712	(18.6%)
Input/Output	11,336	12,281	13,287	8.2%
Dedicated Systems	5,324	5,333	5,481	1.5%
Subtotal	108,941	116,997	125,098	7.2%
Communications				
Premises Telecom Equipment	12,517	13,866	15,102	9.8%
Public Telecommunications	7,175	7,590	8,019	5.7%
Mobile Communications	6,418	6,748	7,083	5.1%
Broadcast and Studio	2,145	2,315	2,465	7.2%
Other	1,660	1,720	1,790	3.8%
Subtotal	29,915	32,239	34,459	7.3%
Industrial				
Security/Energy Management	2,506	2,639	2,822	6.1%
Manufacturing Systems	16,286	16,965	18,538	6.7%
Instrumentation	8,122	8,436	9,142	6.1%
Medical Equipment	6,117	6,485	6,896	6.2%
Civil Aerospace	8,149	9,411	10,807	15.2%
Other	5,719	6,053	6,537	6.9%
Subtotal	46,899	49,989	54,742	8.0%
Consumer				
Audio	285	292	299	2.4%
Video	5,749	5,864	6,014	2.3%
Personal Electronics	239	240	241	0.4%
Appliances	13,147	13,512	13,918	2.9%
Other	1,037	1,078	1,126	4.2%
Subtotal	20,457	20,986	21,598	2.8%
Military	51,727	52,918	54,263	2.4%
Transportation	11,292	11,828	12,897	6.9%
Total	269,231	284,957	303,968	6.3%

Source: Dataquest (August 1990)

Table 4-4

Worldwide Semiconductor Consumption and Consumption Share by Region—1989-1991
(Billions of Dollars and Percent Share)

	Demand ($B)			Demand Share (%)		
Region	1989	1990	1991	1989	1990	1991
North America	17.9	17.2	19.9	31.4%	30.8%	30.3%
Europe	9.8	9.7	11.4	16.9	17.4	17.4
Japan	23.0	22.4	26.1	40.7	40.0	39.8
Asia/ROW	6.5	6.6	8.2	11.0	11.8	12.5
Total	57.2	56.0	65.6	100.0%	100.0%	100.0%

Source: Dataquest (August 1990)

CHAPTER 5

Semiconductor Demand

In 1989, more than $57 billion worth of semiconductor products were consumed worldwide. This demand constituted 12 percent annual growth.

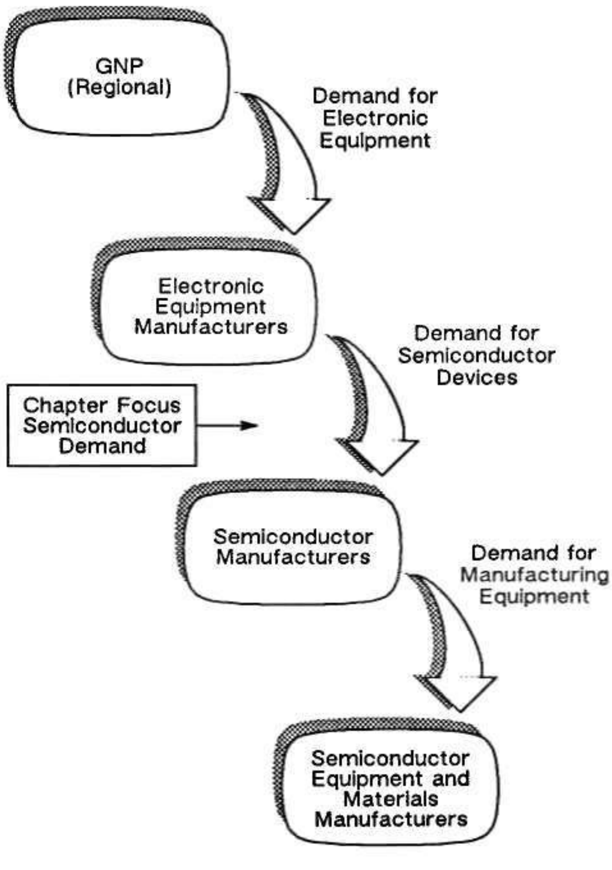
The growth in 1989 followed three years of sustained growth after the 1985 recession, in which merchant demand was only $24 billion. After doubling in the three years between 1985 and 1988 and realizing a 33 percent rate of growth in 1988, the market slowed to only a 12 percent growth rate in 1989.

Although semiconductor demand and production represent the next step down the waterfall of demand (see Figure 5-1), this chapter focuses only on semiconductor demand; Chapter 6 focuses on semiconductor production. This chapter describes the underlying forces that drove semiconductor demand and sustained the extraordinary growth from 1986 to 1989; it also provides the forecast for 1990 and 1991. The chapter contains the following three sections:

- Background—The underlying forces of demand are addressed as follows:
  - Reasons for sustained growth—What has caused the sustained growth in demand over the last three years?
  - Semiconductor producers—Who is satisfying the demand?
  - Demand sources—Where is the demand being generated?
    - Equipment market segments
    - Semiconductor products
    - Geographical regions
- Demand forecast—1990 through 1991 worldwide and regional demand forecast by product type and electronic end-application market, including the economic and end-product demand drivers
- Strategic issues—Key issues relating to the semiconductor demand

Figure 5-1

Waterfall of Demand



Source: Dataquest (August 1990)

Background

Reasons for Sustained Growth—1985 through 1989

Primarily, semiconductor demand growth is a function of equipment production growth. It is assumed that on a worldwide basis, equipment production equals equipment demand, and equipment demand growth is driven by capital spending growth. Figure 5-2 shows the historical correlation between the annual growth of worldwide capital spending, electronic equipment production, and semiconductor consumption for the period from 1970 through 1989. Examination of Figure 5-2 suggests that one contributor to the sustained growth of electronic equipment production was the growth in worldwide capital spending during 1987 and 1988.

The resulting if-sold values of worldwide electronic equipment production and the corresponding semiconductor consumption from 1986 through 1989 are shown in Table 5-1 along with their respective CAGRs. As the table shows, electronic equipment production has increased more than 40.0 percent from its 1986 level, to more than $653 billion in 1989, a 1986 through 1989 CAGR of approximately 12.0 percent. Semiconductor consumption, including captive consumption (defined herein), has doubled its 1986 recession level for a CAGR of 21.5 percent to more than $54 billion in the same period.

Secondarily, the sustained growth in semiconductor demand is from increased semiconductor pervasiveness—particularly in those equipment market (application) segments that represent the highest electronic equipment volume and most rapid growth. Table 5-1 shows that the semiconductor demand value was 7.3 percent of the electronic equipment value in 1986, which increased to more than 8.5 percent by 1988.

Semiconductor Producers

Because semiconductor manufacturers supply their products to electronic equipment producers, within any region, the level of demand for semiconductor products is created by the level of electronic equipment production. More than 200 companies throughout the world supply their products to electronic equipment producers. These companies

Figure 5-2

Worldwide Capital Spending, Electronic Equipment Production, and Semiconductor Demand Growth Rates—1970-1989

Source: Dataquest (August 1990)

Table 5-1

Worldwide Electronic Equipment and Semiconductor Demand—1986-1989

	1986	1987	1988	1989	CAGR 1986-1989
Electronic Equipment Production	$460.4	$525.3	$618.1	$653.1	12.4%
Semiconductor Demand	$ 33.7	$ 41.5	$ 54.5	$60.5	21.5%
Pervasiveness	7.3%	7.9%	8.8%	9.3%	

Note: Includes captive suppliers
Source: Dataquest (August 1990)

can be characterized into one of the following three broad classifications:

- Independent manufacturer
- Division (of a larger corporation) manufacturer
- Captive manufacturer

The first two of these classifications, both of which are merchant suppliers, compete in the worldwide merchant market to supply semiconductor products to manufacturers of electronic equipment worldwide. The third classification—captive—supplies products only for internal consumption to satisfy its own electronic equipment production requirements. These three types of manufacturing companies will be discussed in more detail in Chapter 6. It is important to note that the distinction between merchant and captive suppliers is more prevalent in the United States than in Japan, where most semiconductor production is integrated into a larger electronics company.

Semiconductor Demand Sources

Semiconductor demand can be viewed in the following three ways:

- Demand generated by the individual equipment market application segments
- Demand generated for semiconductor product types
- Demand generated within a geographic region

Equipment Market Segments

Because electronic equipment production creates semiconductor demand, the volume and growth of semiconductor demand by electronic equipment application markets is fundamental to understanding sources of demand growth. The application market segments of electronic equipment production, as defined in Chapter 4, are as follows:

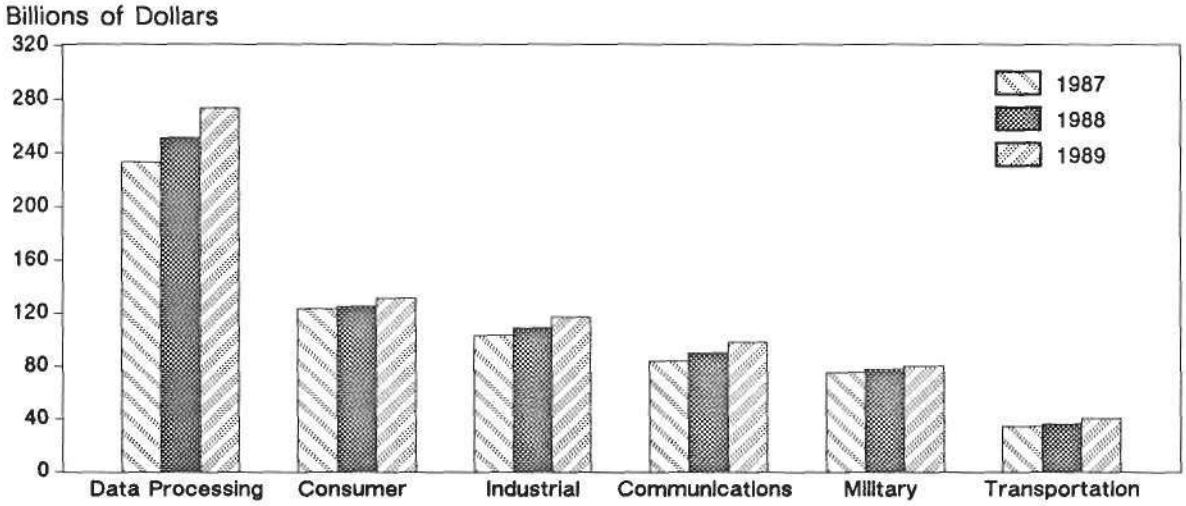
- Data processing
- Communications
- Industrial
- Consumer
- Military
- Transportation

Within the electronic equipment market, the highest growth markets were identified in Chapter 4 to be the data processing, communications, and consumer segments. Figure 5-3 depicts the worldwide electronic equipment market, and Figure 5-4 depicts the resulting semiconductor consumption by electronic equipment market segments for 1987 through 1989. Not surprisingly, the segments with the highest demand and demand growth were the data processing, consumer, and communications segments, and these were also the highest-volume and highest-growth segments of semiconductor demand.

In Figure 5-4, it can be seen that more than two-thirds of the 1989 worldwide semiconductor consumption ($56 billion) has been by producers of data processing, consumer, or communications products. Consumption of semiconductors by these producers has experienced a CAGR of more than 26 percent from 1987 through 1989.

Figure 5-3

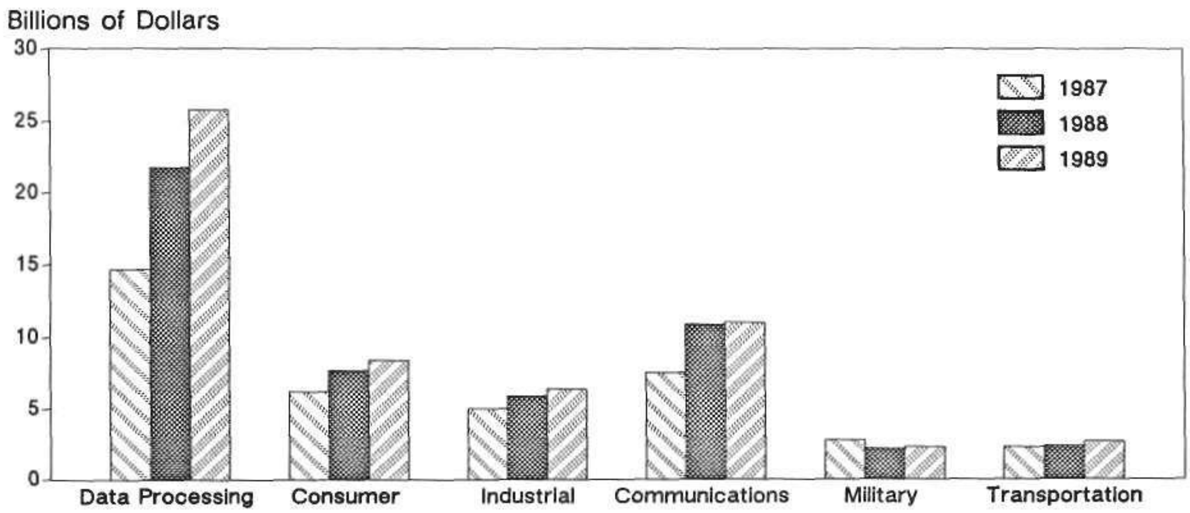
Worldwide Electronic Equipment Market Growth by Application Market Segment—1987-1989



Source: Dataquest (August 1990)

Figure 5-4

Worldwide Semiconductor Demand by Market Segment—1987-1989



Source: Dataquest (August 1990)

Semiconductor Products

In response to semiconductor demand, the semiconductor industry supplies billions of semiconductor devices to electronic equipment producers worldwide. These devices consist of many different types of products, including diodes, transistors, ICs, and optoelectronic devices. Dataquest classifies these products into the following major categories:

- Discrete and optoelectronic devices
- Integrated circuits

Discrete Devices. The term "discrete" refers to a packaged semiconductor device that has a single function, meaning that one or several functioning circuits are in the package. Dataquest divides the discrete market into seven separate categories: small signal and power transistors; small signal, power, and zener diodes; thyristors; and other discretes. Optoelectronic devices include light-emitting diodes (LEDs), photodiodes, solar cells, lasers, optocouplers, and phototransistors.

ICs. An integrated circuit is a single chip that contains more than one active device. For example, it may have a number of transistors, diodes, resistors, or capacitors as part of an electronic circuit. Integrated circuits vary widely by function. They can perform digital or linear electronic functions and may be based on a number of basic technologies, such as bipolar or MOS.

Dataquest further classifies ICs into memory, microcomponents, logic, and analog. These categories are described in the following paragraphs with some examples of commercially available product types.

Memory ICs. Memory ICs are designed for the storage and retrieval of binary information. Read/write memory, generally referred to as random-access memory (RAM), allows storage and retrieval of information created by the user. When such information is retained only as long as power is supplied to the device, the memory device is referred to as "volatile." Examples of volatile memory products are as follows:

- Dynamic RAM (DRAM)
- Static RAM (SRAM)
- Hierarchical RAM (HRAM)

Examples of nonvolatile memory products, which do not lose information when power is removed, are the following:

- Read-only memory (ROM)
- Programmable read-only memory (PROM)
- Erasable PROM (EPROM)
- Electrically erasable PROM (EEPROM)

Microcomponents. Microcomponents are further categorized into microprocessors, microcontrollers, and microperipherals, as follows:

- Microprocessor (MPU)—A microprocessor can be a single chip or a collection of chips that function together as the central processing unit (CPU) of a system.
- Microcontroller (MCU)—A microcontroller is an IC containing a CPU, memory, and input/output (I/O) capability; it can perform all the basic functions of a computer without the additional ICs.
- Microperipheral (MPR)—Microperipherals are support devices for microprocessors or microcontrollers. They either interface external equipment or provide system support. Examples are as follows:
  - Disk-drive controllers
  - PC logic chip sets
  - Graphics controllers
  - Bus controllers
  - Serial and parallel I/O controllers

Logic Devices. Logic may be visualized as the "glue" that surrounds the IC devices discussed previously. They handle digital signals in a variety of ways: routing, multiplexing, demultiplexing, encoding/decoding, counting, and comparing. Logic devices also are used to implement I/O interfaces. They are divided into two categories—standard and ASIC—shown as follows:

- Standard logic—Standard logic ICs are readily available off the shelf from a number of suppliers. They come in predefined logical functions in a variety of arrangements. Examples of standard logic types are as follows:
  - Bipolar
    - Transistor-transistor logic (TTL)
    - Emitter-coupled logic (ECL)
  - Metal-oxide semiconductor (MOS)
- ASICs—ASICs are integrated circuits designed or adapted by the user for a specific application or set of logical functions. Examples of ASIC types are as follows:
  - Programmable logic devices (PLDs)
  - Gate arrays

- Cell-based design
- Full-custom design

Semiconductor Demand by Product—1988 through 1989

The worldwide semiconductor demand and demand growth by product category are shown in Table 5-2. The major category with the highest growth from 1988 to 1989 is that of optoelectronic devices, with a growth rate of 20.6 percent. The table also shows that the market for discrete products declined 0.7 percent between 1988 and 1989. ICs, which represent more than 80 percent of total product consumption, posted a growth rate of 14.3 percent during the same period. Table 5-2 includes consumption of products manufactured by merchant market suppliers. If a manufacturer supplies the merchant market and captive producers, the consumption of its entire production is included. Manufacturers that exclusively supply captive producers are not included in these consumption figures.

Within the IC category, both the largest-volume and the highest-growth area was MOS digital products, with a growth rate of 22.4 percent. MOS digital products represent more than one-half (57.7 percent) of total semiconductor consumption. Within this category, MOS memories showed a growth rate of 39.9 percent, whereas MOS microcomponents and logic experienced a growth rate of 14.8 percent and 3.8 percent, respectively. MOS memories represent nearly 29.0 percent of total semiconductor consumption, whereas microcomponents and logic devices together represent almost 30.0 percent.

Table 5-3 lists the top ten semiconductor products in terms of annual growth in 1989 over 1988. These ten products had an aggregate annual growth of 28.0 percent in 1989 over 1988. The remaining products grew only 3.3 percent over 1988.

The electronic equipment products driving the demand for these highest-growth semiconductor products are PCs, small-scale computers, technical workstations, graphics workstations, personal peripherals such as disks and small laser printers, and LANs that tie all of these desktop systems together.

Table 5-2

Worldwide Semiconductor Consumption—1988-1989
(Millions of Dollars)

	1988	1989	Growth 1988-1989
Total Semiconductor	$50,859	$57,213	12.5%
Total IC	$41,068	$46,924	14.3%
Bipolar Digital	$ 5,200	$ 4,510	(13.3%)
Memory	689	540	(21.6%)
Logic	4,511	3,970	(12.0%)
MOS Digital	$26,988	$33,024	22.4%
Memory	11,692	16,361	39.9%
Micro	7,144	8,202	14.8%
Logic	8,152	8,461	3.8%
Analog	$ 8,880	$ 9,390	5.7%
Total Discrete	$ 7,612	$ 7,662	(0.7%)
Total Optoelectronic	$ 2,179	$ 2,627	20.6%

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1990)

Table 5-3

Top Ten Demand Growth Semiconductor Products
1989 over 1988

Product	Annual Growth
MOS ASIC—PLD	53%
MOS DRAM Memory	46%
MOS Specialty Memory	41%
MOS SRAM Memory	29%
MOS ASIC—Gate Arrays	20%
MOS ASIC—CBIC	17%
MOS Microperipherals	15%
MOS Microcontrollers	14%
Bipolar ASIC—CBIC	14%
Bipolar ASIC—Gate Array	13%
Aggregate Annual Growth	28%
All Other Products	3.3%

Note: Excludes captive demand
Source: Dataquest (August 1990)

The demand for MOS DRAM memories, fast 32-bit microprocessors, ASICs, and other MOS microcomponents grew so rapidly during late 1987 and early 1988 that a serious supply shortage existed. Although this supply shortage eased in 1989, these products still are in great demand and their growth continued in 1989. The 1990 and 1991 demand forecast for these products appears in the subsection entitled "Semiconductor Demand Forecast—1990 and 1991."

The shortage of DRAMs and SRAMs and the associated price inflation of these devices has had a substantial impact on both the magnitude of the overall semiconductor demand growth and the role that MOS digital products have in the semiconductor industry. DRAMs make up so much of the semiconductor sales volume that variations in their price can inflate or deflate the overall industry sales volume, causing distorted views of growth or decline.

MOS Memory

The "Swing Vote" in the Semiconductor Industry

DRAMs make up so much of the semiconductor sales volume that they have become the "swing vote" in determining the health of the industry. In fact, DRAM prices can have a monumental impact on the overall industry sales volume and result in skewed growth or decline numbers.

During 1984, the Japanese production capacity for MOS memory expanded voraciously as the perceived PC boom appeared to be creating a huge demand for 64K DRAMs. When the bubble burst in 1985, the Japanese producers continued their high-volume production, and the supply far exceeded the demand. The 256K part also was coming onstream at that time, and the Japanese producers were anxious to push this more profitable part. Triggered by rapid price slashing, first by Micron in the United States and then by various Japanese suppliers, the price of both 64K and 256K devices plummeted during 1985 and 1986.

Faced with severe unprofitability, the major remaining US DRAM producers, with the exception of Micron and TI, withdrew from the market. The US producers, through the SIA, succeeded in gaining US government support for their accusation that the Japanese were "dumping" 64K devices (i.e., selling them at prices well below cost).

This resulted in the US-Japan Semiconductor Trade Arrangement of 1986, which required that Japan not participate in the practice of dumping and that Japan's MITI manage the Japanese production to balance supply with demand to force the DRAM prices to stabilize so that US producers could compete. It is interesting to note that when the DRAM prices were stabilized by raising prices, the effect was to generate huge additional profits for Japanese producers to reinvest in new technology. The other major element of the agreement was that Japan would actively assist the US producers in obtaining at least a 20 percent share of its market for semiconductors.

The results of this agreement are questionable, at best. MITI reduced production of DRAMs through most of 1987, and demand recovered as US and global economies heated up; by mid-1987, demand far exceeded supply and the prices of DRAMs and SRAMs were uncharacteristically high. Early in 1990, we witnessed a number of agreements between large Japanese and American semiconductor suppliers, aimed at increasing market share for US vendors in Japan.

Perhaps the best result of this agreement was the development of long-term buyer-seller agreements and dialogue that were designed to prevent the recurrence of the 1984 disaster. The objective of this new procurement-supply process was to supply and adhere to long-term forecasts on both sides of the table, thus stabilizing both the buyers' inventory control and the vendors' production scheduling.

As the PC boom of late 1987 and 1988 moderated in early 1989 and MITI advised higher production levels, the supply of MOS memories balanced demand within the first two quarters of 1989. At that time, a considerable decline in memory prices occurred, which amplified the perceived decline in semiconductor demand through 1989 and 1990 just as the inflated pricing of DRAMs in 1987 and 1988 inflated the extraordinary growth during that period.

Semiconductor Demand by Region—1988 through 1989

The worldwide semiconductor demand by region for merchant sales only is shown in Table 5-4. This table illustrates that the combined demand from the Japanese and Asia/ROW regions was $29.5 billion in 1989, or 51.6 percent of the 1989 total demand. The North American demand was more than $17.9 billion or 31.4 percent of the total. The 1985 figures are quite different. In 1985—only four years earlier—Japan and Asia/ROW represented $11.0 billion, or only 38.0 percent of the $29.0 billion total, whereas the North American demand was $13.0 billion for a 45.0 percent share.

Although the North American region has declined somewhat since 1985 as a consumer of electronic equipment relative to Japan and the Asia/ROW countries, its share of electronic production has fallen much further, as indicated by the decline in semiconductor demand share from 45.0 percent to 31.4 percent. This sharp decline in North America's share of semiconductor consumption is discussed further in the subsection entitled "What Caused the Regional Shift in Worldwide Semiconductor Demand from 1985 through 1989?"

Semiconductor Demand Forecast—1990 and 1991

The worldwide economic outlook developed in Chapter 3 highlighted a deceleration of growth of real GNP/GDP starting in mid-1989 and continuing through 1990. Beyond 1990, a healthy recovery period is forecast. The impact of this deceleration in capital spending, electronic equipment production, and semiconductor demand growth worldwide is shown in Figure 5-5. The specific impact of capital spending on worldwide equipment production by application market was discussed in Chapter 4 and is reviewed in Figure 5-6.

After experiencing a growth rate of 5.7 percent in 1989, electronic equipment production growth is expected to be slightly slower in 1990, at 5.6 percent. In 1990, Dataquest expects a stronger growth rate of 7.3 percent. Figure 5-5 also forecasts the resulting worldwide demand for semiconductors to decline 0.7 percent in 1990 after a 10.9 percent growth rate in 1989 and to rebound to grow 17.1 percent in 1991.

Table 5-4

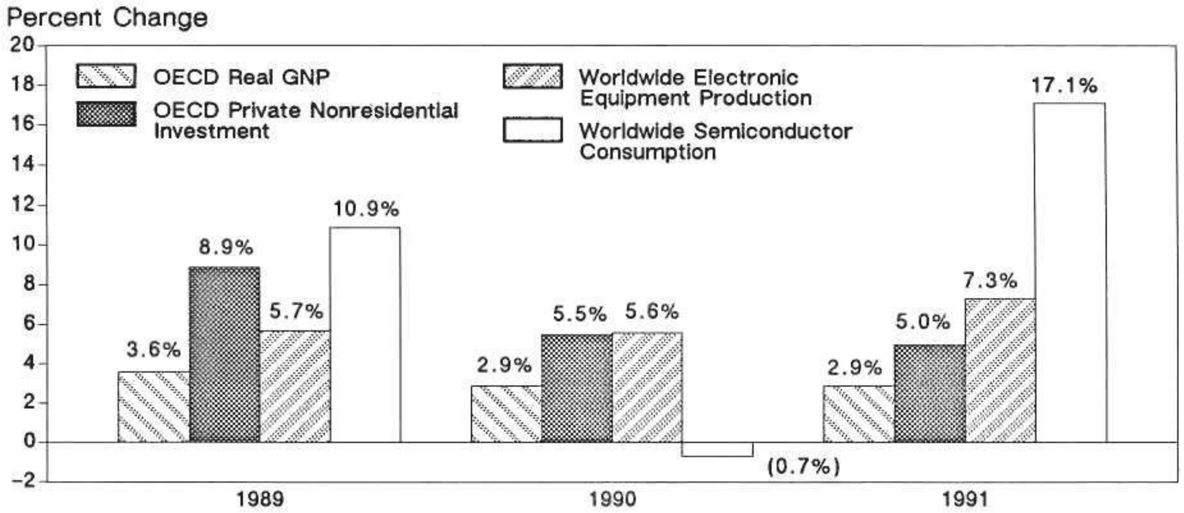
Regional Semiconductor Consumption—1988-1989 (Millions of Dollars)

Region	1988	1989	Percent Share 1989	Growth 1988-1989
North America	$15,844	$17,937	31.4%	13.2%
Japan	20,772	22,997	40.2	10.7%
Europe	8,491	9,755	17.0	14.9%
Asia/ROW	5,752	6,524	11.4	13.4%
Total	$50,859	$57,213	100.0%	12.5%
Annual Growth	33.0%	12.5%		

Note: Excludes captive demand
Source: Dataquest (August 1990)

Figure 5-5

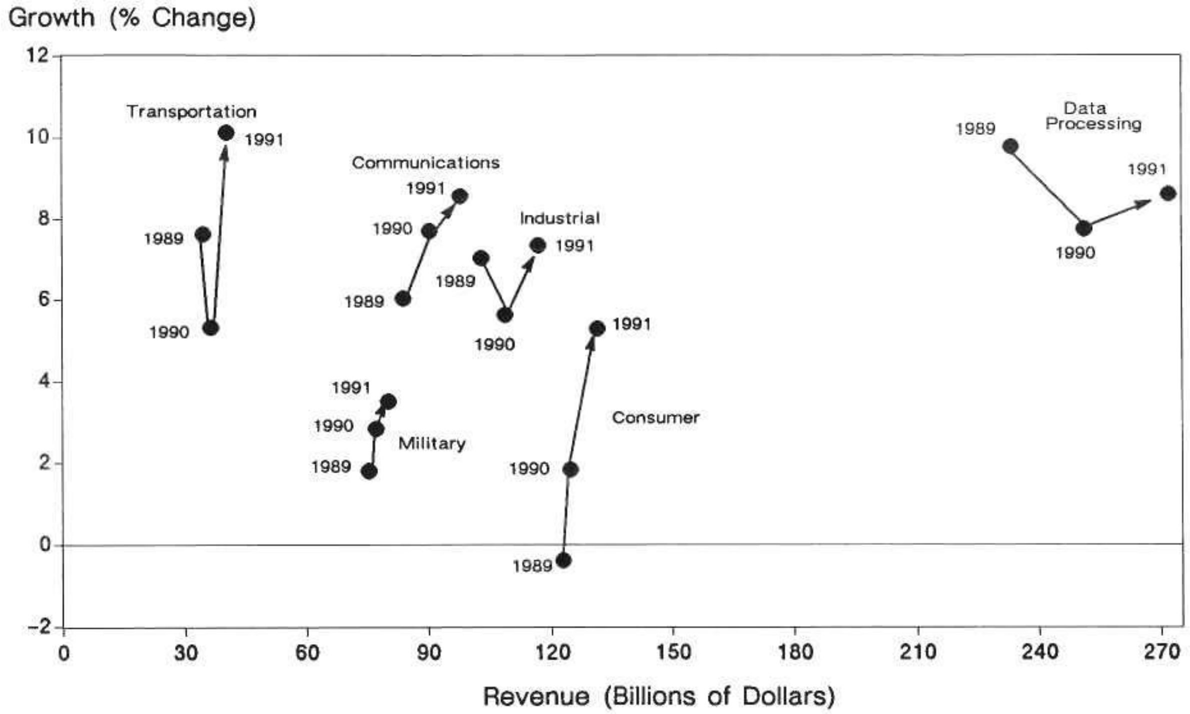
Estimated Changes in Economic, Electronic Equipment Production, and Semiconductor Consumption Growth—1989-1991



Source: Dataquest (August 1990)

Figure 5-6

Growth Trends for Applications Segments—Worldwide



Source: Dataquest (August 1990)

Worldwide Semiconductor Demand Forecast by Product—1990 and 1991

Table 5-5 presents the worldwide demand estimate and forecast by semiconductor product. The total demand CAGR for 1989 through 1991 is 8.0 percent. Total MOS digital ICs are forecast to grow at a CAGR of 9.0 percent from 1989 to 1991, driven by growth in logic, memory, and microcomponent products. In addition, analog IC products are expected to have a CAGR of 9.7 percent for that period. Bipolar memory is forecast to decline steadily through the period as it is replaced by BiCMOS memory for high-performance applications. In general, Table 5-5 shows significant growth across all product areas except bipolar digital ICs from 1989 to 1991 as the industry recovers from two slow growth years. Dataquest expects a 16.5 percent growth rate for the total semiconductor market in 1991.

Worldwide Semiconductor Demand Forecast by Region—1990 and 1991

Table 5-6 presents the 1990 and 1991 forecast and 1989 actual numbers by region. Not surprisingly, the Asia/ROW region is forecast to enjoy the highest growth, with a CAGR of 14.8 percent; Europe should enjoy the next highest growth, with a 13.1 percent CAGR. Japan is forecast to have a CAGR of 5.3 percent, barely behind the North American region's estimated 6.0 percent. Also notice that the Asia/ROW region is expected to enjoy a 23.1 percent growth rate in 1991.

North American Demand Forecast—1990 and 1991

After a slow first half, the semiconductor market in 1990 is expected to show significant growth by year's end, with 4.9 percent and 5.4 percent increases in demand for the third and fourth quarters, respectively. On the whole, Dataquest anticipates a negative 3.1 percent growth rate in 1990. Demand growth will decline to 2.4 percent in the first quarter of 1991, followed by strong 5.2 percent growth in the second quarter. Continued strong growth is expected in the second half of 1991, yielding a 16.2 percent growth rate for the year.

Table 5-7 presents the North American forecast by semiconductor product for 1990 and 1991, along with the actual 1989 numbers. The total North American semiconductor market is expected to grow 16.4 percent in 1990, with a CAGR of 6.0 percent for the period 1989 to 1991. In addition, the total IC market is forecast to grow 17.7 percent in 1990, with a CAGR of 6.2 percent for the 1989 to 1991 period. The dominant influence is, of course, MOS memory, which will drive a 19.7 percent growth in the MOS digital category from 1990 to 1991. After a 5.7 percent decline from 1989 to 1990, the addition of the 1991 growth yields a CAGR of only 6.3 percent for

Table 5-5

Worldwide Semiconductor Consumption by Product—1989-1991
(Millions of Dollars)

	1989	1990	1991	Growth 1990/1991	CAGR 1989-1991
Total Semiconductor	$57,213	$57,265	$66,720	16.5%	8.0%
Total IC	$46,924	$46,543	$54,966	18.1%	8.2%
Bipolar Digital	4,510	4,135	4,427	7.1%	(9.2%)
MOS Digital	33,024	32,549	39,235	20.5%	9.0%
Analog	9,390	9,859	11,304	14.7%	9.7%
Total Discrete plus Optoelectronic	$10,289	$10,722	$11,754	9.6%	6.9%

Note: Excludes captive consumption
Source: Dataquest (August 1990)

Table 5-6

Regional Semiconductor Consumption—1989-1991
(Millions of Dollars)

Region	1989	1990	1991	Percent Share 1989	Percent Share 1991	Growth 1990/1991	CAGR 1989-1991
North America	$17,937	$17,312	$20,154	31.4%	30.2%	16.4%	6.0%
Japan	22,997	22,287	25,498	40.2	38.2	14.4%	5.3%
Europe	9,755	10,678	12,469	17.0	18.7	16.8%	13.1%
Asia/ROW	6,524	6,988	8,599	11.4	12.9	23.1%	14.8%
Total	$57,213	$57,265	$66,720	100.0%	100.0%	16.5%	8.0%
Annual Growth	12.5%	0.1%	16.5%				

Note: Excludes captive consumption
Source: Dataquest (August 1990)

Table 5-7

North American Semiconductor Consumption—1989-1991
(Millions of Dollars)

	1989	1990	1991	Growth 1990/1991	CAGR 1989-1991
Total Semiconductor	$17,937	$17,312	$20,154	16.4%	6.0%
Total IC	$15,909	$15,225	$17,927	17.7%	6.2%
Bipolar Digital	1,701	1,567	1,651	5.4%	(1.5%)
MOS Digital	11,682	11,021	13,190	19.7%	6.4%
Analog	2,526	2,637	3,086	17.0%	10.5%
Total Discrete plus Optoelectronic	$2,028	$2,087	$2,227	6.7%	4.8%

Note: Excludes captive consumption
Source: Dataquest (August 1990)

the 1989 to 1991 period. Also showing substantial demand growth is the market for analog ICs. Demand is expected to grow 17.0 percent in 1991, with a CAGR of 10.5 percent from 1989 to 1991. As is the case in the worldwide market, the demand for bipolar digital ICs shows a general decline throughout the period.

Four Strategic Issues

What Are the Semiconductor Demand Drivers?

The driving force behind the 1990 and 1991 demand forecast (shown in Table 5-5) is MOS memory, particularly DRAMs and SRAMs. DRAM prices have dropped significantly since the first half of 1989, especially for 1Mb devices, but they appear to be stabilizing. Thus, DRAM demand growth in dollar terms is forecast at negative 32.0 percent for 1990 and at positive 28.0 percent for 1991 when measured on a year-to-year basis. Unit growth is forecast at a negative 5.7 percent for 1990.

This forecast is very dependent on DRAM pricing assumptions because, as mentioned earlier, DRAMs make up such a large portion of the product mix. This dependency and the underlying pricing assumptions are discussed in the following paragraphs.

Products within the data processing segment—PCs, technical workstations, graphics workstations, and medium-scale business computers—are driving much of the DRAM/SRAM demand. New applications for MOS memories are emerging that include digital copiers, digital fax machines, digital VCRs, and extended-definition TV (EDTV).

The outlook for microcomponents and MOS logic is significantly different. Because the PC industry is expected to have slower growth during 1990 than in 1989, microprocessor growth should be correspondingly slower, at 6.4 percent in 1990, down from 14.5 percent in 1989 and 14.6 percent in 1991. MOS logic growth is forecast at 8.5 percent in 1990 and 20.5 percent in 1991.

Optoelectronic and discrete devices, primarily used in communications and consumer electronic products, are forecast to have moderate growth. Optoelectronic growth is expected to be 4.0 percent growth in 1990 and 16.1 percent in 1991. Discrete devices are projected to experience a 2.8 percent growth in 1990 and an 11.0 percent growth in 1991.

What Caused the Regional Shift in Worldwide Semiconductor Demand from 1984 through 1989?

The regional demand for semiconductors has changed dramatically over the last four years. A summary of key points follows:

- In 1984, Japan and the Asia/ROW countries represented $11 billion, or only 38 percent of the $29 billion total, whereas North American demand in 1984 was $13 billion for a 45 percent share.
- The 1984 North American demand for electronic equipment constituted 44 percent of the worldwide equipment demand, while Japan and Asia/ROW's share was only 21 percent. By 1989, the North American equipment demand fell to 40 percent, and the Japanese and Asia/ROW share climbed to 27 percent.
- The North American share of electronic production fell much further, as indicated by the decline in semiconductor demand share from 45 percent to 31 percent.

There are three primary causes for this dramatic shift. First, North American equipment producers moved offshore. By 1984, most of the consumer electronics producers had moved their production to Asian sites where the low cost of labor was more favorable to high productivity and competitiveness. Many data processing, communications, and industrial equipment suppliers either had done the same or were having subassemblies manufactured offshore for final assembly and test in North America. This ongoing shift of US equipment production to more favorable economic climates is one obvious cause of the observed shift in semiconductor demand (see Chapters 2 and 4 for further information).

Second, a shakeout occurred among US suppliers. In 1985, a 15.6 percent decline took place in worldwide semiconductor demand, and a precipitous 28.0 percent decline occurred in US demand. Much of the observed shift in regional semiconductor demand occurred in this 1985 and 1986 recession period, which suggests an additional cause for the observed shift.

To find the additional cause requires digging deeper into the events surrounding 1984 through 1986. Chapter 4 identified 1984 as a boom year, particularly for relatively new producers of PCs and related equipment and communications equipment producers. Excessive demand accounted for the apparent success of many of these producers. But when the demand fell off in 1985, their fundamental lack of competitiveness could not withstand the onslaught of Japanese and Asia/ROW competitors in a declining market. As a result, many of these new US equipment producers fell by the wayside rather suddenly during 1985 and 1986.

Any slack in the supply from this shakeout of new US equipment producers was filled quickly by their Asia/ROW and Japanese counterparts. The former US demand for semiconductors suddenly shifted to

Asia and Japan as the "victor's" equipment sales filled the void.

The third primary cause for this dramatic shift in demand share to Japan has been the change in the exchange rate caused by the devaluation of the dollar beginning in 1986. Indexed against the 1984 exchange rate of 237 yen/dollar, the volume in yen of the worldwide semiconductor demand increased only 33 percent from its 1985 level. The Japanese share has increased far less than otherwise observed in terms of current dollars.

As a result of these circumstances, the Asia/ROW region experienced the highest demand CAGR from 1986 to 1989, followed by Japan, Europe, and the United States. Thus, the extraordinary sustained growth in semiconductor demand from 1985 to 1989 was by and large enjoyed in Japan and the Asia/ROW countries, although all regions experienced healthy growth during the period.

What Is the Impact of Regional Economic Conditions on Semiconductor Demand for 1990 and 1991?

The following paragraphs summarize Chapter 3's detailed forecasts of each region's economic climate and Chapter 4's analysis of the impacts of these forecasts on each region's electronic equipment demand and production and relates them to the regional forecast of semiconductor demand given in Table 5-6. For more detailed information, please refer to the appropriate chapter.

North America

The US economy grew 3.0 percent in terms of real GNP in 1989. The real capital spending growth in 1989 was nearly 4.1 percent over 1988 and is forecast to increase slightly less than 4.3 and 4.4 percent for 1989 and 1990, respectively. North American electronic equipment production grew 6.0 percent in 1989. However, because of the slowing of capital spending and reduced competitiveness in export markets, electronic equipment production growth in the United States is projected at 5.8 percent in 1990 before rebounding to 6.4 percent in 1991.

This estimate assumes that the exchange-rate-derived competitiveness of US equipment producers continues to enable them to at least hold their existing market share of export markets in Europe. As the US dollar rises, US electronic exports become less competitive in foreign markets. As 1990 unfolds, US interest rates, labor costs, and inflationary pressures suggest that US fundamental competitiveness will be challenged during the expected period of reduced worldwide market for electronic equipment.

If the US dollar rises very much above 160 yen/dollar and 2 deutsche marks/dollar in 1990, the impact of this effective price increase in Europe and Asia, coupled with higher domestic costs, could invalidate the forecast level of export and thus reduce the actual equipment production to be less than what was forecast.

From Dataquest's estimates of the North American growth of electronic equipment production by application segment, the data processing and communications segments should realize the highest growth over the forecast period, led by PCs and related peripherals, high-performance graphics workstations, and LANs. Growth of the data processing equipment segment is forecast at 7.5 percent for 1990; growth of communications is projected at 7.8 percent.

As expected from the data presented in the previous paragraphs, the North American semiconductor demand's highest segments are data processing, communications, and industrial. However, by far the most influential end product in the North American semiconductor demand forecast is the personal computer.

That the production of PCs is critical to the health of US semiconductor demand is easily appreciated when one considers that PCs alone account for more than 11.0 percent of North American semiconductor consumption. Dataquest's North American semiconductor demand forecast is based on the forecast that the unit quantity of PCs produced in the United States will decline to 8.5 percent growth in 1990 from 1989's 14.3 percent growth rate. Dataquest expects growth of PC unit shipments to increase, posting a growth rate of 9.3 percent in 1991.

Japan

The Japanese economy is strong but slowing, with a 1989 annual growth of 4.8 percent, down from a rate of 5.7 percent in 1988. This growth is expected to decline slightly over the forecast period to 4.5 percent in 1990 and 4.3 percent in 1991. This estimate assumes some decrease in Japanese exports and a continued healthy growth in imports.

The Japanese domestic electronic production growth rate therefore is expected to climb to 1.4 percent in 1990 after a 0.3 percent decline in 1989, followed by 4.9 percent growth in 1991.

The Japanese marketing strategy is to focus its sales of consumer products on its still-buoyant domestic demand while aiming sales of computers, communications, and industrial equipment to export markets.

The requisite export level to sustain the forecast GNP growth assumes that the Japanese economy will continue to sustain historic productivity levels. Japanese competitiveness as an exporter and even as a domestic supplier will be challenged because of the strong yen and increasing costs within Japan. However, many Japanese producers have moved portions of their equipment production offshore to Thailand, Malaysia, and Singapore to reduce costs and assure competitiveness both domestically and worldwide.

Despite challenges to Japanese competitiveness, the primary growth segment of equipment production will be data processing, which is forecast to grow 4.3 percent in dollar terms in 1990 before increasing to 7.2 percent growth in 1991. New applications such as EDTV, point-of-sale (POS) terminals (required by Japanese retailers to handle the new sales tax), and various high-performance consumer products are expected to provide growth in the near fugure.

The forecast decline in Japan's electronic production growth rates is the result of the following:

- The shifting of a portion of Japan's equipment production to the Asia/ROW and European regions
- The reduction of export levels due to the strong yen and the need to balance Japan's trade surplus
- The slowing of demand from the United States and Europe as a result of the forecast global economic "soft landing" in 1990

Japanese semiconductor demand will decline 2 percent in 1990, before experiencing a 16 percent growth in 1991 (see Table 5-6). The reduced 1990 growth in dollar terms is the direct result of declining DRAM prices and reduced electronic equipment growth, resulting from Japanese electronic manufacturing shifts to Asia and Europe.

Europe

The GNP/GDP of the OECD European countries enjoyed moderate 3.5 percent growth in 1989 but is forecast to decrease to 2.8 percent in 1990 and 2.7 percent by 1991. Annual capital spending growth will fall to 5.2 percent in 1990 and decrease slightly to 5.1 percent by 1991. Preparations for the unified 1992 European market will sustain a higher level of electronic equipment demand than would otherwise be expected under the global economic slowdown expected through the forecast period. During the next four years, the European market offers some unique opportunities and challenges. Many local and multinational companies, including those from the United States, Japan, and the Asia/ROW region, are building production facilities in Europe to take advantage of Europe 1992. These facilities will purchase semiconductors locally to receive favorable tax treatment, so additional semiconductor production capacity is building up in Europe as well. Because of this 1992 effect, some additional electronic equipment production and the resultant semiconductor consumption will shift into Europe from the other regions during 1990 and 1991.

PCs were the driving force for European semiconductor demand growth, particularly in MOS microcomponents, memory, and bipolar digital logic. PC production accounts for more than 50.0 percent of Europe's DRAM consumption. Order rates from European PC manufacturers have been low since the middle of 1989 and have continued into the first half of 1990. Despite this decline in IC demand from PC vendors, Europe is forecast to increase semiconductor consumption by 9.5 percent in dollar terms in 1990 (due mainly to exchange rate fluctuations) and to sustain a 16.8 percent growth in 1991.

Asia/ROW

The Asia/ROW countries are forecast to experience a slight decline in real GNP/GDP growth from their historic double-digit growth levels to the 4.5 to 7.5 percent range during 1990 and 1991. Both consumer and capital spending are forecast to remain robust as these economies continue their course of rapid expansion through export. Because North America constitutes a large portion of their export market (40.0 percent), some slowing in exports is expected in 1990, but this could be offset by increased exports to China, Thailand, and other developing countries.

As mentioned previously, the Asia/ROW region also is the beneficiary of much of the Japanese consumer equipment producers' move offshore to sustain competitiveness. A portion of its equipment production growth forecast reflects this shift in production from Japan.

The primary drivers of semiconductor demand in the Asia/ROW region are PC and consumer product production. Recent softness in North American and European PC demand caused semiconductor demand to slow in 1989 and early 1990. Considerable consumer product production growth is forecast over the next two years, as the domestic markets of China and Thailand begin to open up.

Thus, Asia/ROW semiconductor demand is forecast to decline from the 8.9 percent growth rate in 1989 to a 6.1 percent growth rate in 1990 before realizing 24.9 percent growth in 1991.

What Are Price and Availability for Critical Devices?

The key semiconductor devices to be under pressure for price and availability appear to be memory-related: DRAMs and SRAMs. Some concern will exist about price and availability of high-performance 32-bit microprocessors, but with the expected slowdown in the computer industry, it will not be too strong.

Single-source manufacturers of 32-bit MPUs incur large R&D expenses while developing these products and then must pay huge fab costs to produce the chips. Consequently, suppliers of 32-bit MPUs fiercely resist abrupt price declines during the growth stage of the product life cycle (unlike the reality of the semiconductor memory business). Instead, once volume production starts, 32-bit MPU suppliers fight to hold prices relatively high for several quarters or more—at least until a significant portion of new product costs have been recaptured. Product pricing can drop somewhat quickly during the mature stage before stabilizing.

Suppliers of 32-bit MPUs are ramping up output and cutting prices of 20-MHz and 25-MHz products during 1990. Prices for mature 16-MHz products have been more stable. Dataquest expects pricing to edge down for Motorola's 68020 products during 1991. We expect pricing for the 68030 to move sharply at the end of 1990 and the beginning of 1991. In contrast, users of Intel's 80386 products can expect a rather flat product price profile in 1991.

As 1989 progressed, lower orders from equipment producers caused a decline in both unit quantity and ASP growth. Dataquest expects 1Mb DRAM pricing to move downward throughout 1990, although at a slower rate than in late 1989 and the first half of 1990. We anticipate the 4:1 unit/price crossover to 4Mb DRAMs from 1Mb parts to occur in North America during the first quarter of 1991. At that time, Dataquest forecasts that the price of 4Mbx1 devices will be $24.10 and that of the 1Mbx1 will be slightly less than $6.00. The recent cutbacks in 1Mb DRAM production capacity cloud the 1991 DRAM outlook. Even so, most recent surveys indicate that several large and dependable suppliers of 1Mb DRAMs plan to reduce prices throughout the forecast period, reaching a price of slightly less than $4.95 by the fourth quarter of 1991.

CHAPTER 6

Semiconductor Production

In 1989, more than $57 billion worth of semiconductor products were manufactured worldwide. The semiconductor industry supplies billions of individual semiconductor devices to satisfy semiconductor demand generated by worldwide electronic equipment producers. These devices consist of many different types of semiconductor products including diodes, transistors, ICs, and optoelectronic devices.

More than 200 companies throughout the world produce semiconductor devices. These companies range in size, products, and marketing strategies from giant multinational corporations engaged in volume production of commodity ICs to much smaller companies addressing specialized market niches.

Despite their diversity, semiconductor companies share a common purpose: the miniaturization of electronic devices through the use of semiconductor materials. The technology behind this industry involves elements of physics, chemistry, and electronic theory that are at the cutting edge of their respective disciplines.

This chapter describes the underlying forces that influence semiconductor production. The chapter is organized into the following three sections:

- Background—The underlying forces of production are addressed as follows:
  - What are the key characteristics of semiconductor manufacturing?
    - Two-stage process
    - Cost and investment structure
    - High-cost wafer fabs
    - Offshore shift of back-end process
    - Demand for high-volume technology driver
  - Who manufactures semiconductors?
  - Where are semiconductors manufactured?
- Production forecast—1989 and 1990 worldwide and regional production forecast by region and location of company headquarters
- Strategic issues—Key issues and opportunities relating to the semiconductor production forecast

Background

Key Characteristics of Semiconductor Manufacturing

In general, semiconductors are manufactured in two major stages:

- The front-end (wafer fabrication) process
- The back-end (device assembly and test) process

The Front-End or Wafer Fabrication Process

The front-end process is a complex sequence involving hundreds of individual process steps that transform bare silicon wafers to fully fabricated wafers made up of multiple integrated circuits. For example, a state-of-the-art 1Mb DRAM process can have as many as 200 to 300 process steps with 15 or more mask layers.

During the semiconductor manufacturing process, the bare silicon wafer is processed through a repetitive sequence of thin film deposition, photolithographic patterning, and etching steps. A series of masks containing the circuit design information are used to transfer the IC pattern into silicon. The fabrication process is carried out in an extremely clean environment to eliminate defects that would otherwise render the IC nonfunctional. The final IC consists of thousands of transistor devices that are connected together in a specified pattern to perform the desired electrical function. Each processed wafer contains multiple rows of identical IC chips that also are known as die. The wafer can now be diced into individual chips and packaged.

The Back-End or Test-and-Assembly Process

The first part of the back-end process consists of electrically testing the finished wafers to check all the chips for adherence to the circuit functional specifications. The bad chips are dotted with ink and will be rejected from subsequent assembly processing. Next, the wafer is diced and the good chips are separated and assembled in ceramic or plastic packages for connection to the outside board-level circuits. The finished integrated circuit package finally is tested again to check for functional performance before being shipped to the customer.

Equipment and supplies (materials) necessary for semiconductor production are categorized as fron-end and back-end equipment and materials. (For further information about semiconductor manufacturing equipment and materials, see Chapter 7.)

Cost and Investment Structure

The manufacturing cost and investment structure for the semiconductor manufacturing process can be characterized as follows:

- Massive capital investment in wafer fab (front end) capacity
- Considerable labor cost for test and assembly (back-end process)
- Materials costs associated with the procurement of the raw silicon wafers and packages

Manufacturing costs are determined by the variable or per-unit cost in terms of materials and labor cost, and the amortization of the fixed capital investment. The biggest impact is that of the amortization. Thus, true profitability and return on investment are critically dependent on the efficiency of the process, or how many devices can be produced for a given fixed investment cost.

Another way of saying this is the profit and return on investment (ROI) of a semiconductor producer is most dependent on the yield from the manufacturing process. (Yield is the number of saleable devices expressed as a percentage of the total devices produced.) Obviously, the higher the yield, the higher the efficiency, and therefore the higher the profit and ROI.

Manufacturers continually seek to improve yields. Many techniques are used, but such improvements most often are the result of new manufacturing technology. The semiconductor equipment suppliers provide the new technology and therefore are critical contributors to the success of semiconductor producers.

High-Cost Wafer Fabs

Because of the high cost of wafer fabs, the semiconductor manufacturing industry is undergoing structural change. In the past, semiconductor producers typically performed all or most of the production steps themselves. Today, however, some newer companies are separating the device design function from the device fabrication process. Such companies add value through innovative design and customer service as opposed to improved manufacturing.

Among companies that possess manufacturing capabilities, marked differences exist in the number of support functions they integrate into the fab process. Such support functions include fabrication of the packaging in which the devices are assembled, growing and preparing the raw silicon wafers, manufacturing the masks used in the photolithographic process, and other related functions. Larger and older companies such as IBM or TI tend to be more integrated. Smaller and newer companies tend not to perform as many of these functions. Intel, for example, purchases masks, wafers, and packages.

Recently, there has been a proliferation of companies offering semiconductor manufacturing services. These include device design, maskmaking, wafer fabrication (wafer foundries), assembly and packaging, and testing services. These companies make it possible to design, manufacture, and market semiconductors without the huge investment in manufacturing equipment, CAD/CAM equipment, or engineering manpower. They serve the needs of other semiconductor manufacturers and semiconductor users alike.

Another reason for the structural changes described previously is the projected increase in wafer fab productivity. Dataquest estimates that by the year 2000, the if-sold value potential of a modern wafer fab facility will be as high as $670 million. This would seem to limit such investments to only the top few billion-dollar companies and encourage "foundry-for-hire" agreements among many other companies.

Offshore Shift of Back-End Process

Japanese semiconductor producers leveraged their economy's superior productivity characteristics—low interest rates, patient capital, and low-cost, highly skilled labor—and developed a competitive edge on US producers. In response, US semiconductor producers transplanted labor-intensive assembly operations offshore to Asia/ROW countries. Today, it is not unusual for wafers to be fabricated in one country, devices assembled in a second, and final testing and shipping to occur in a third. This mobility within the manufacturing process is made possible by the small size and low weight-per-dollar value of semiconductor devices.

This search for the lowest-cost allocation of production resources has led increasingly more companies to invest in overseas assembly plants. This trend is expected to continue, although it eventually may be slowed by increased automation of the assembly process.

Demand for High-Volume Technology Driver

Dataquest's Semiconductor Equipment and Materials Service (SEMS) estimates that because of their huge production volumes, particularly in MOS DRAMs, Japanese producers have as much as a 70 percent cost advantage over US producers. This advantage has the following two primary sources:

- Japan frequently has brought new products through the development process into the market ahead of the United States. This allows Japanese manufacturers to move down the learning curve and to charge lower prices than US suppliers once the latter enter the market. The only way the United States can catch up is to produce significantly higher volumes.

- Most important is that Japanese producers have a decided advantage over their competition in manufacturing yields. At the heart of the yields issue is the need for leading-edge, high-volume products that can serve as technology drivers that improve yields for all products. Since the early 1980s, MOS DRAMs have served this function for semiconductor producers. The United States lost most of its DRAM market share to the Japanese by 1986. Since then, Japan has exploited its massive DRAM production technology for superior yields and the resultant cost advantages in many other products.

Who Manufactures Semiconductors?

More than 200 semiconductor manufacturers exist throughout the major geographical regions. These companies can be classified as follows:

- Independent manufacturers
- Divisions of major corporations
- Captive manufacturers

The first two of these classifications compete in the worldwide merchant market to supply semiconductor products to electronic equipment producers worldwide. Captive manufacturers supply products only for internal consumption to satisfy a company's own electronic equipment production requirements. It is important to note that the merchant and captive supplier classifications are more of a US notion than a Japanese one. In Japan, most semiconductor production is integrated within larger electronics companies.

As mentioned previously, the search for the lowest manufacturing cost has forced producers to become international in scope, at least in manufacturing. The high capital investment required is creating a restructuring of the type of services and products offered as well.

Independent Manufacturers. Most manufacturing (about 70 percent in the United States) is performed by independent manufacturers. Semiconductor manufacturing and sales constitute the major part of their businesses. Their survival depends on their performance in the semiconductor industry. They have no guaranteed markets or financing. In general, they are aggressive, competitive, and innovative in bringing new technologies to market. Companies in this category include Advanced Micro Devices (AMD), Intel, Motorola, National Semiconductor, and TI.

Divisions of Major Corporations. Many major corporations in the United States, Japan, and Europe have divisions that produce semiconductors. These divisions are distinct from captive producers because they actively sell their devices on the open market (merchant market). Most, but not all, of these companies market at least a small portion of their output to their parent companies. All benefit from the financial resources of the parent, which is a distinct advantage considering the huge capital requirement that characterizes semiconductor production.

In some cases, these companies also have the advantage of a small sheltered market (to the parent) for some of their products. On the other hand, they can suffer from parental management decisions that are not in their best interests or that fail to reflect an understanding of semiconductor business issues.

In Japan, these companies are referred to as integrated. The Japanese companies have skillfully combined the financial strength of the parent company, the integration of device design with end-product design to maximize end-product performance and competitiveness, and the cost benefits of volume-production devices for the merchant market. In Japan, both the integrated semiconductor producer and the parent equipment manufacturer win.

Worldwide examples of semiconductor divisions of major corporations include AT&T, Harris, Hitachi, NCR, Nippon Electric (NEC), Philips, Rockwell, Siemens, Toshiba, and Westinghouse.

Captive Manufacturers. Companies that maintain semiconductor manufacturing facilities for production of devices solely for their own use are referred to as captive manufacturers. As semiconductors become more important to major equipment manufacturing companies, these companies are realizing the value of captive facilities that allow device design to be integrated with final system design, thus maximizing the leverage of the underlying silicon.

Many of these captive facilities provide services and unique devices that are not available in the merchant market. That is, they define device requirements based on final system requirements, then design and make what they cannot buy. Captive manufacturers fulfill semiconductor demand that is not available to the other suppliers to the merchant market.

Examples of captive manufacturers are General Motors, Hewlett-Packard, IBM, and Unisys.

Top Ten Worldwide Semiconductor Manufacturers

Table 6-1 shows the overall ranking of the top ten worldwide semiconductor producers by total 1989 revenue. Figure 6-1 shows the revenue growth from the top ten companies from 1987 through 1989. Several items are noteworthy, including the following:

- The number one producer—NEC—has increased its revenue by nearly 50 percent since 1987.

- Of the top three producers, Toshiba has experienced the highest growth rate since 1987, at 62.8 percent, and has firmly established itself in the number two position.

- None of the US companies in the top ten recorded 1989 growth rates that exceeded the industry average of 12 percent. Motorola was the highest at 9 percent, followed by Intel and TI with growth rates of 3 and 2 percent, respectively. In addition, both TI and Intel slipped one place in the market share rankings, to sixth and eighth, respectively. By contrast, each Japanese manufacturer in the top ten, with the exception of Matsushita, experienced growth rates of at least 10 percent.

- Mitsubishi recorded the highest growth rate, 72.9 percent, of any company in the top ten from 1987 to 1989. In doing so, the company moved from number nine to number seven in two years.

- Two companies in the top ten, Matsushita and Philips, experienced negative growth in 1989.

Another important industry characteristic that is shown in Table 6-1 is that of market concentration, which is illustrated in Figure 6-2. This figure shows that the top 10 companies garnered 55.2 percent market share; the top 25 accounted for more than 80.0 percent of the market. The remaining companies (ranked 26 through 136) accounted for only 18.5 percent of the market.

Company Market Shares by Product Category

The products driving growth in 1989 were MOS DRAMs and SRAMs, MOS microcomponents, and MOS ASICs. Tables 6-2 through 6-8 rank the top ten producers in the following major semiconductor product classifications: total integrated circuit, total bipolar digital, total MOS digital, MOS memory, analog ICs, discretes, and optoelectronics.

The Japanese Example:
The Advantage of Integrated Producers over Independent Producers

Japan's mostly integrated semiconductor producers' rapid rise to dominance over the United States' mostly independent semiconductor producers provides empirical evidence that the Japanese model works best. The Japanese model, however, was very much influenced by the IBM company model, and the IBM model included integrated semiconductor production.

As mentioned in Chapter 5, Japan's national objective was to develop its electronic equipment production to a world-class level. Data processing, consumer, and communications were the chosen market segments. As a strategy, Japan licensed product technologies and manufacturing rights, then leveraged its superior economic competitiveness and manufacturing acumen to gain foreign market share through aggressive pricing.

In 1975, the goal of this strategy became dominance over US semiconductor producers. This entailed the cooperative efforts of the MITI, sources of patient capital, and a variety of large electronic equipment producers that were chosen to participate in the development of the Japanese semiconductor industry as integrated producers.

The semiconductor strategy of the Japanese integrated producers was not dissimilar to their equipment strategy and is outlined as follows:

- Capitalize on the innovations of the independent US producers by obtaining licenses to the technology and/or manufacturing rights as a second source
- Focus on MOS DRAMs as the necessary technology driver
- Advance the technology through simplification, thereby reducing manufacturing costs and increasing quality and reliability. In so doing, leapfrog US independent producers and bring 64K DRAMs to the market ahead of them
- Exploit the advantages provided by Japan's more competitive economic climate and its sheltered environment provided by MITI's protection of the Japanese market, the huge financial resources of the parent companies, and the patience of investment capital, by increasing foreign market share through aggressive pricing

This was devastating to US independent DRAM suppliers. In 1975, 15 US manufacturers supplied nearly all of the worldwide market; by 1986, all but 2 had been shaken out of the market. The remaining 2 retained less than a 25 percent share of the entire memory market by 1987. This happened because the Japanese producers won large shares of the 16K DRAM market through aggressive pricing and superior quality from 1978 through 1980 and were first to market with 64K devices in 1980. In 1982, they announced sampling of the 256K MOS DRAM, and subsequently all but the aforementioned 2 US producers withdrew from DRAM production from 1982 through 1985.

Can US Standalone Semiconductor Producers Survive?

We have presented empirical proof that integrated semiconductor producers have inherent advantages over independent producers. Independents, of course, can argue that only in their environment can the innovations and new products that advance the industry be created and developed, and they may be right. However, at this point, the question is becoming academic and is being replaced with another much more important one: Does the standalone semiconductor producer concept of the United States—a product of the entrepreneurial spirit that is the backbone of the free enterprise system—have long-term viability in view of the superior financial resources, government support, and current market shares of the Japanese integrated producers?

The challenge for the United States is how to quickly devise ways to match the superior resources of the Japanese integrated producers while operating within the boundaries of the free enterprise system.

Table 6-1

Top Ten Worldwide Semiconductor Manufacturers for 1989

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	NEC	4,543	5,015	10%
2	2	Toshiba	4,395	4,930	12%
3	3	Hitachi	3,506	3,974	13%
4	4	Motorola	3,035	3,319	9%
5	6	Fujitsu	2,607	2,963	14%
6	5	Texas Instruments	2,741	2,787	2%
7	8	Mitsubishi	2,312	2,579	12%
8	7	Intel	2,350	2,430	3%
9	9	Matsushita	1,883	1,882	0
10	10	Philips	1,738	1,716	(1%)
		North American Companies	18,586	19,978	7%
		Japanese Companies	15,942	29,809	15%
		European Companies	4,917	5,443	11%
		Asia/ROW Companies	1,414	1,983	40%
		Total World Companies	50,859	57,213	12%

Source: Dataquest (August 1990)

In the MOS digital category (see Table 6-4), the remarkable growth experienced by Samsung, moving from 11th to 9th in the ranking is due to the ramping up of its DRAM production. In MOS memory, Sharp and Intel exchanged rankings, with Sharp moving from 10 to 8, due to Sharp's participation in the DRAM market and Intel's lack of participation.

In general, companies that are strong in MOS memory continued to dominate the market. Figure 6-3 shows the pecentage of revenue attributed to MOS memory for the top five worldwide semiconductor suppliers.

Where Are Semiconductors Produced?

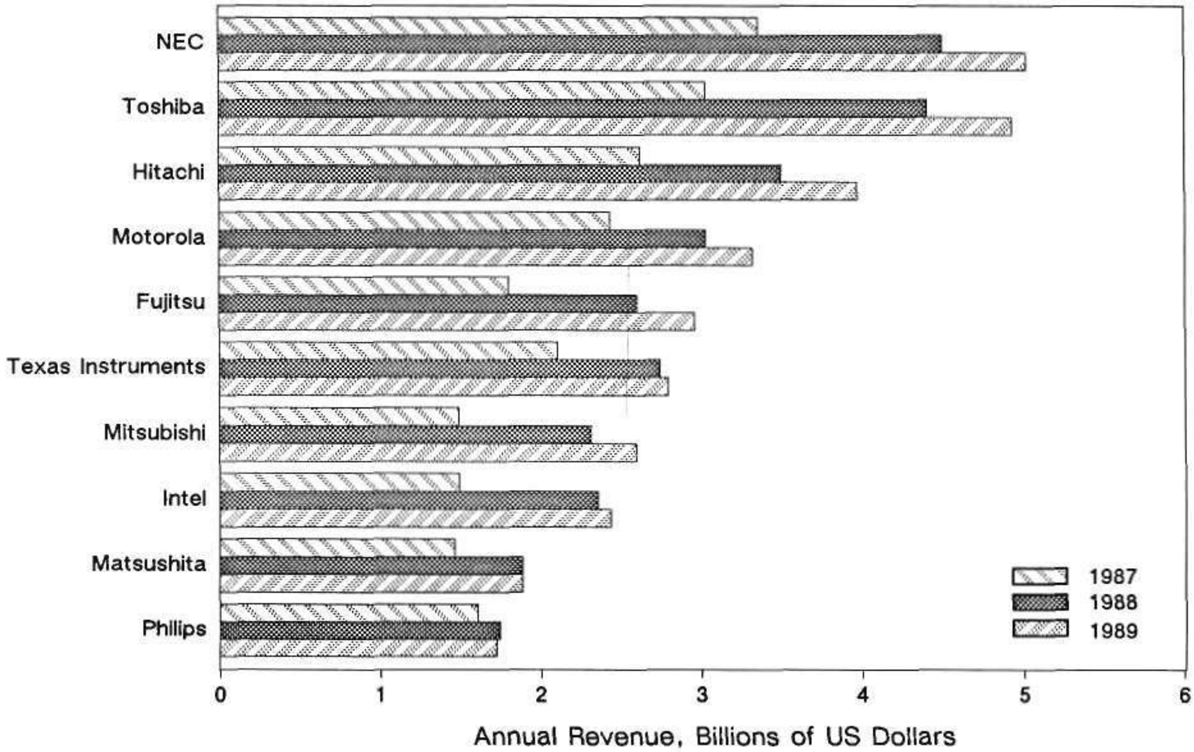
The United States was the semiconductor innovator, and it concentrated on building a dominant industry infrastructure within the country during the early years of industry development. In 1974, the United States controlled an estimated 62 percent of the total world semiconductor market and more than 75 percent of the worldwide IC segment. Including the market represented by US captive producers, the total semiconductor market figure was more than 80 percent.

Through the highly focused efforts of the Japanese integrated producers, initially on DRAMs and subsequently on most other products, the situation looked substantially different by 1990. Figure 6-3 shows that in 1989, the Japan-based companies accounted for more than 52 percent of the total semiconductor market; the share of US-based companies had fallen to 35 percent of the merchant market.

Europe-based companies' share of the world market also declined, from 17.0 percent in 1974 to less than 10.0 percent in 1989, while the share of companies based in Asia/ROW countries captured a 3.5 percent market share in 1989, up from zero in 1980.

Table 6-9 compares the market share of companies based in the United States by major product category in 1980 and 1987. Table 6-10 shows the impact of 1989 growth on these figures and reflects the increasing presence of the Asia/ROW companies in the MOS digital category as the US producers' share continued to decline.

Figure 6-1
Worldwide Semiconductor Market Share
Top 10 Companies—1987-1989
(Billions of Dollars)



Source: Dataquest (August 1990)

Table 6-11 shows the regional semiconductor demand as developed in Chapter 5 and the share of each region's demand supplied by regional company base for 1988 through 1989. As Table 6-11 shows, the US companies' share of the total US demand declined from 70 percent in 1988 to 65 percent in 1989. The Japanese companies' share of US consumption increased from 21 to 26 percent in the same period, while the Asia/ROW countries maintained their 3 percent share.

However, US companies' share of the Japanese market remained relatively constant at approximately 9 percent in 1988 and 1989, while the Japanese companies' share of the Japanese market remained a dominant 90 percent. Japanese and Asia/ROW countries increased their penetration of the European market considerably, from 19 percent in 1988 to 22 percent in 1989.

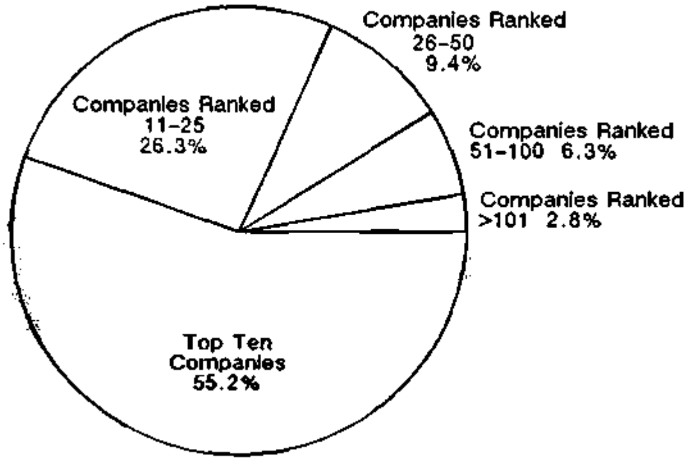
While North American companies' market share in the Asia/ROW region held at 32 percent between 1988 and 1989, the Asia/ROW region increased its market share in their own region. At the same time, Japanese market share fell from 45 percent in 1988 to 41 percent in 1989.

Why the Shift to the Pacific Rim?

Of the numerous reasons for the increased market share of Japanese and Asian producers over the past ten years, the primary one is Japan's focused strategy embodied in its aggressive penetration of the DRAM market, as mentioned previously. Second is the US companies' transfer of large portions of their manufacturing operations to foreign plants. The accompanying technology transfers have then enabled foreign producers to advance these technologies rapidly, thereby diminishing US technical superiority.

Figure 6-2

1989 Worldwide Semiconductor Market Share
Concentration of Revenue



Source: Dataquest (August 1990)

Table 6-2

1989 Worldwide Semiconductor Market Share Ranking
Total Integrated Circuit
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	NEC	3,884	4,321	11%
2	2	Toshiba	3,3163	3,774	14%
3	3	Hitachi	2,729	3,218	18%
4	5	Fujitsu	2,420	2,738	13%
5	4	Texas Instruments	2,637	2,691	2%
6	7	Motorola	2,259	2,519	12%
7	6	Intel	2,350	2,430	3%
8	8	Mitsubishi	1,975	2,185	11%
9	9	National Semiconductor	1,575	1,548	(2%)
10	11	Philips	1,281	1,250	(2%)
		North American Companies	15,990	17,400	9%
		Japanese Companies	20,375	23,800	17%
		European Companies	3,429	3,915	14%
		Asia/ROW Companies	1,274	1,809	42%
		Total World Companies	41,068	46,924	14%

Source: Dataquest (August 1990)

Table 6-3

1989 Worldwide Semiconductor Market Share Ranking
Total Bipolar Digital
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Texas Instruments	940	671	(29%)
2	4	Fujitsu	653	617	(6%)
5	5	Hitachi	501	479	(4%)
4	3	Advanced Micro Devices	536	474	(12%)
3	2	National Semiconductor	550	458	(17%)
6	6	Motorola	435	369	(15%)
7	7	Philips	413	306	(26%)
8	8	NEC	292	302	3%
9	10	Mitsubishi	127	125	(2%)
10	9	Plessey	94	122	30%
		North American Companies	2,761	2,221	(20%)
		Japanese Companies	1,791	1,755	(2%)
		European Companies	598	502	(16%)
		Asia/ROW Companies	50	32	(36%)
		Total World Companies	5,200	4,510	(13%)

Source: Dataquest (August 1990)

Table 6-4

1989 Worldwide Semiconductor Market Share Ranking
Total MOS Digital
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	NEC	3,123	3,604	15%
2	2	Toshiba	2,639	3,100	17%
3	3	Intel	2,328	2,420	4%
4	4	Hitachi	1,885	2,407	28%
5	5	Fujitsu	1,616	1,958	21%
6	7	Motorola	1,399	1,705	22%
7	6	Mitsubishi	1,453	1,676	15%
8	8	Texas Instruments	1,271	1,603	26%
9	11	Samsung	765	1,066	39%
10	10	Oki	841	1,028	22%
		North American Companies	9,754	11,277	16%
		Japanese Companies	14,494	18,006	24%
		European Companies	1,684	2,135	27%
		Asia/ROW Companies	1,056	1,606	52%
		Total World Companies	26,988	33,024	22%

Source: Dataquest (August 1990)

Table 6-5

1989 Worldwide Semiconductor Market Share Ranking
MOS Memory
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	2	Toshiba	1,516	1,918	27%
2	1	NEC	1,490	1,739	17%
3	4	Hitachi	1,114	1,534	38%
4	3	Fujitsu	1,067	1,265	19%
5	5	Mitsubishi	966	1,161	20%
6	6	Texas Instruments	834	1,095	31%
7	7	Samsung	650	935	44%
8	10	Sharp	344	476	38%
9	9	Oki	353	473	34%
10	8	Intel	392	433	10%
		North American Companies	2,836	3,688	30%
		Japanese Companies	7,597	10,558	39%
		European Companies	464	786	69%
		Asia/ROW Companies	795	1,329	67%
		Total World Companies	11,692	16,361	40%

Source: Dataquest (August 1990)

Table 6-6

1989 Worldwide Semiconductor Market Share Ranking
Total Analog Integrated Circuits
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Toshiba	569	572	1%
2	2	National Semiconductor	540	558	3%
3	3	Sanyo	471	530	13%
4	5	Philips	466	522	12%
5	7	Motorola	425	445	5%
6	6	Texas Instruments	426	417	(2%)
7	4	NEC	469	415	(12%)
8	11	SGS-Thomson	352	493	12%
9	9	Mitsubishi	395	384	(3%)
10	8	Matsushita	423	376	(11%)
		North American Companies	3,475	3,902	12%
		Japanese Companies	4,090	4,039	(1%)
		European Companies	1,147	1,278	11%
		Asia/ROW Companies	168	171	2%
		Total World Companies	8,880	9,390	6%

Source: Dataquest (August 1990)

Table 6-7

1989 Worldwide Semiconductor Market Share Ranking
Discrete
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Toshiba	864	848	(2%)
2	2	Motorola	752	775	3%
3	3	Hitachi	707	690	(2%)
4	4	NEC	571	574	1%
5	5	Philips	432	442	2%
6	7	Mitsubishi	310	364	17%
7	5	Matsushita	377	332	(12%)
8	8	Rohm	287	301	5%
9	9	Fuji Electric	279	287	3%
10	10	SGS-Thomson	254	282	11%
		North American Companies	2,171	2,120	(2%)
		Japanese Companies	4,056	4,091	1%
		European Companies	1,250	1,284	3%
		Asia/ROW Companies	135	167	24%
		Total World Companies	7,612	7,662	1%

Source: Dataquest (August 1990)

Table 6-8

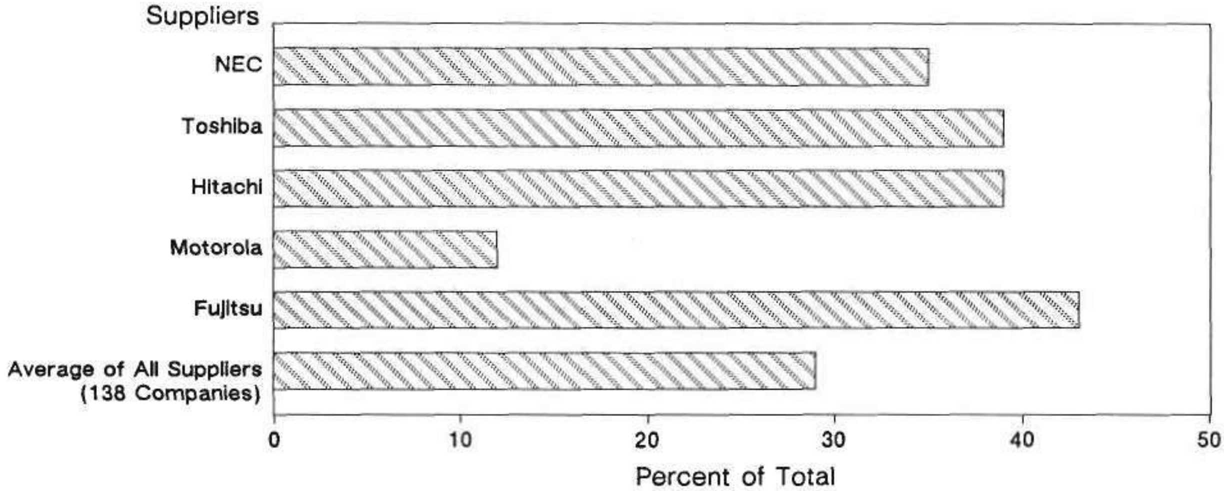
1989 Worldwide Semiconductor Market Share Ranking
Optoelectronic
(Millions of Dollars)

1989 Rank	1988 Rank	Company	1988 Revenue	1989 Revenue	Percent Change
1	1	Sharp	285	328	15%
2	3	Toshiba	215	308	43%
3	5	Matsushita	178	306	72%
4	2	Sony	217	249	15%
5	4	Hewlett-Packard	213	213	0
6	12	Sanyo	62	160	158%
7	9	NEC	88	120	36%
8	7	Fujitsu	105	116	10%
9	8	Siemens	100	115	15%
10	6	Rohm	109	96	(12%)
		North American Companies	425	458	8%
		Japanese Companies	1,511	1,918	27%
		European Companies	238	244	3%
		Asia/ROW Companies	5	7	40%
		Total World Companies	2,179	2,627	21%

Source: Dataquest (August 1990)

Figure 6-3

Worldwide Semiconductor Market Shares by Company Base



Source: Dataquest (August 1990)

Table 6-9

US Producers' Market Share—1980 and 1987

	1980	1987	Percent Change
Total Semiconductors	57.2%	39.0%	(18.2%)
Total Integrated Circuits	62.7%	42.0%	(20.7%)
Total Bipolar Digital	75.5%	55.0%	(20.5%)
Total MOS Digital	62.3%	41.0%	(21.3%)
MOS Memory	73.7%	28.0%	(45.7%)
Total Analog	46.5%	39.0%	(7.5%)
Total Discrete	43.5%	31.0%	(12.5%)

Source: Dataquest (August 1990)

With the maturation of the industry as reflected by high-volume commodity products, the United States has not had a sufficiently productive economic environment to manufacture commodity semiconductors competitively. Many difficulties also are associated with satisfying the short-term perspective of the US investment community. The constant need to provide a quick return makes it hard for independent US producers to match the manufacturing resources and expertise of Japanese producers that have integrated relationships with large, diversified, and multinational parent companies that allow more favorable economies of scale, lower profit margins, and ready access to more patient capital.

Another basic problem for US chip producers is the rapidly declining US demand for semiconductors (see Chapter 5). This decline, combined with the considerable increase in demand from the Pacific Rim and Japan, is forcing US producers to depend less on domestic consumption of their products and turn toward more effective penetration of these regions.

Table 6-10

US Producers' Market Share—1987 and 1989

	1987	1989	Percent Change
Total Semiconductors	39.0%	34.9%	(4.1%)
Total Integrated Circuits	42.0%	37.1%	(4.9%)
Total Bipolar Digital	55.0%	49.2%	(5.8%)
Total MOS Digital	41.0%	34.1%	(6.9%)
MOS Memory	28.0%	22.5%	(5.5%)
Total Analog	39.0%	42.6%	2.6%
Total Discrete	31.0%	27.7%	(3.3%)

Source: Dataquest

Table 6-11

Worldwide Semiconductor Consumption by Region and Regional Company Share of Production—1988-1989 (Millions of Dollars)

	1988	1989	Market Share 1988	Market Share 1989
Regional Consumption				
North America				
North American Companies	11,146	11,715	70%	65%
Japanese Companies	3,277	4,574	21	26
European Companies	1,006	1,025	6	6
Asia/ROW Companies	415	623	3	3
Total North American Market	15,844	17,937	100%	100%
Japan				
North American Companies	1,965	2,162	9%	9%
Japanese Companies	18,640	20,628	90	90
European Companies	115	130	1	1
Asia/ROW Companies	62	77	0	0
Total Japanese Market	20,772	22,997	100%	100%
Europe				
North American Companies	3,664	4,032	43%	41%
Japanese Companies	1,466	1,924	17	20
European Companies	3,196	3,562	38	37
Asia/ROW Companies	165	237	2	2
Total European Market	8,491	9,755	100%	100%

(Continued)

Table 6-11 (Continued)

Worldwide Semiconductor Consumption by Region and
Regional Company Share of Production—1988-1989
(Millions of Dollars)

	1988	1989	Market Share 1988	Market Share 1989
Asia/ROW				
North American Companies	1,811	2,069	32%	32%
Japanese Companies	2,569	2,683	45	41
European Companies	600	726	10	11
Asia/ROW Companies	772	1,046	13	16
Total Asia/ROW Market	5,752	6,524	100%	100%
Worldwide Production				
North American Companies	18,586	19,978	37%	35%
Japanese Companies	25,942	29,809	51	52
European Companies	4,917	5,443	9	10
Asia/ROW Companies	1,414	1,983	3	3
Total Worldwide Market	50,859	57,213	100%	100%
Annual Growth Rate	31.9%	12.5%		

Notes: Some columns may not add to totals shown because of rounding.
Merchant sales only
Source: Dataquest (August 1990)

To the extent that historic barriers to penetrating these regional markets militate against successful US competition in these regions, US producers and the US government need to cooperate more closely to level the playing field. However, this need must be balanced against the adverse aspects of protectionist legislation. In striking this balance, care must also be taken not to blame an unlevel field for lost market share that is more the result of fundamental noncompetitiveness than trade barriers.

Semiconductor Production Forecast—1990 and 1991

Regional Companies' Semiconductor Forecast—1990 and 1991

The 1990 and 1991 forecast for semiconductor production by regional company base is shown in Table 6-12. This forecast includes captive production. Dataquest forecasts that the demand slowdown discussed in Chapter 5 will cause total production—including captives—to decline by 0.5 percent in 1990, but rebound to grow 16.9 percent in 1991.

Table 6-12 shows the stabilization of North American companies' share of worldwide merchant and captive production. After slowly eroding throughout the 1980s, indications now show that this erosion is slowing. Between 1989 and 1991, US producers have a forecast CAGR of 7.3 percent. Their share of total production during the period 1989 through 1991 will remain the same at approximately 39 percent.

On the other hand, Japanese companies' share of total production is projected to decline from 47.8 percent in 1989 to 44.8 percent in 1991. Most of this decline can be attributed to price erosion in MOS memories. For the same reason, Japanese companies' total output is forecast at a CAGR of only 4.3 percent through the forecast period.

Table 6-12

Worldwide Semiconductor Production Forecast
Regional Company Share—1989-1991
(Millions of Dollars)

	1989	1990	1991	Production Share 1989	Production Share 1991	CAGR 1989-1991
Worldwide Production						
North American Companies	24,044	23.586	27,707	39.8%	39.4%	7.3%
Japanese Companies	28,930	28,093	31,489	47.8	44.8	4.3%
European Companies	5,468	5,868	7,199	9.0	10.2	14.7%
Asia/ROW Companies	2,038	2,613	3,952	3.4	5.6	39.3%
Total Worldwide Market	60,480	60,160	70,347	100.0%	100.0%	100.0%
Annual Growth Rate	10.9%	(0.5%)	16.9%			

Note: Includes captive production
Source: Dataquest (August 1990)

Regional Production Regardless of Manufacturers' Home Base—1989 through 1992

The production forecast of companies headquartered in each of the four regions was given in the previous subsection. However, it also has been indicated that many companies are moving their production facilities to other regions to avoid trade barriers, achieve lowest assembly cost, and get closer to the demand. Examples of this are the fab facilities owned by US and Japanese companies being built in Asian countries such as Singapore and Thailand, and Japanese facilities being built in Europe and the United States.

Therefore, the true semiconductor production within a given region is the total production within the borders of the region, regardless of the home base of the producer. It is this production level that establishes the capital spending within a region and thus establishes the total regional available market for semiconductor manufacturing equipment and materials.

Figure 6-4 shows Dataquest's estimate of such regional semiconductor production from 1989 through 1991. Table 6-13 compares the 1984 regional production share with the 1991 production share forecast. The table shows that despite the increase of Japanese and European fabs in North America, the region's share of worldwide semiconductor production will fall to approximately 35 percent in 1991, much less than the 49.8 percent share enjoyed in 1984, and significantly less than the 45.0 percent of total production from within Japan's borders.

Four Strategic Issues Regarding the Semiconductor Production Forecast

Impact of Regional Imbalances

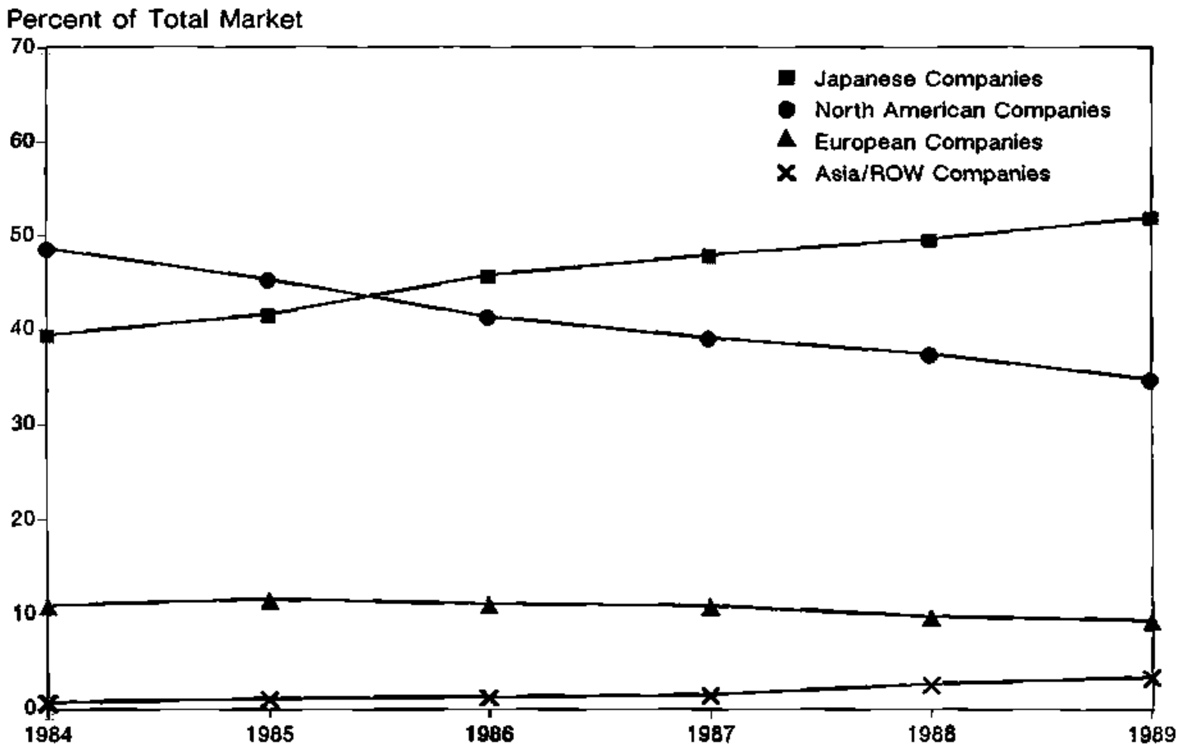
Table 6-14 compares the total semiconductor demand (including that of captives) by region with the regional production regardless of regional company base (including captives) for 1986, 1989, and 1991. As the table indicates, the difference between production and demand is net exports. The following conclusions can be drawn from the table:

- As a result of preparations for 1992, Europe is substantially increasing its ratio of production to demand, so European producers' share of the European demand is expected to increase from 63.9 percent in 1989 to 80.8 percent in 1991.
- Japan is reversing the historical trend of increasing its ratio of Japanese production to Japanese demand. This ratio peaked in 1989 at 127 percent and should decline to 120 percent by 1990. This again is attributed mostly to MOS memory price declines, but is also because of the increasing share of the European demand being supplied by European companies.

- Asia/ROW companies' share of their own market is forecast to increase from 29.7 percent in 1986 to 52.1 percent by 1990.
- The major export opportunities for the US companies are the Asian ROW and European markets. The combined demand is forecast to more than double between 1990 and 1993. It is critical that US producers increase their share of both markets for their forecast level of production to be realized. It is also critical that the exchange rate of the dollar against the yen and deutsche mark remain at or below today's levels (less than 160 yen/dollar and 2 deutsche marks/dollar)

Figure 6-4

Worldwide Semiconductor Production by Region Regardless of Producers' Home Region



Source: Dataquest (August 1990)

Table 6-13

Worldwide Semiconductor Production by Region

	1984	1991
North America	49.8%	35.1%
Japan	38.3	45.0
Europe/ROW	11.9	19.9
Total	100.0%	100.0%

Source: Dataquest (August 1990)

Table 6-14

Regional Imbalances in Electronic Equipment Demand and Production—1986, 1989, 1991

Region	Demand Millions of Dollars	Demand Percent	Net Exports Millions of Dollars	Production Millions of Dollars	Production Percent	Ratio of Production to Demand
1986						
North America	13,171	39.0%	1,285	14,456	42.9%	109.8%
Europe	5,992	17.8	(2,161)	3,831	11.4	63.9%
Japan	12,018	35.6	2,668	14,686	43.5	122.2%
Asia/ROW	2,548	7.6	(1,792)	756	2.2	29.7%
	33,729	100.0%	0	33,729	100.0%	
1989						
North America	20,978	34.7%	780	21,758	36.0%	103.7%
Europe	10,105	16.7	(3,313)	6,792	11.2	67.2%
Japan	23,134	38.3	6,253	29,387	48.6	127.0%
Asia/ROW	6,263	10.3	(3,720)	2,543	4.2	40.6%
	60,480	100.0%	0	60,480	100.0%	
1991						
North America	23,785	33.8%	887	24,672	35.1%	103.7%
Europe	12,042	17.1	(2,307)	9,735	13.8	80.8%
Japan	26,318	37.4	5,346	31,664	45.0	120.3%
Asia/ROW	8,202	11.7	(3,926)	4,276	6.1	52.1%
	70,347	100.0%	0	70,347	100.0%	

Note: Includes captive production
Source: Dataquest (August 1990)

Opportunities for Semiconductor Producers

Based on the patterns of electronic equipment demand (and therefore, that of semiconductor product categories) outlined in Chapters 4 and 5, the following are the most interesting new product opportunities for the next few years:

- ASICs
- Specialty memories and ferroelectric RAMs (FERRAMs)
- Intelligent power devices
- Microcomponents

ASICs

Although still relatively small today, the ASIC market is forecast by Dataquest to grow at a CAGR of nearly 19 percent through 1993, at which time it should reach sales of more than $15 billion. This forecast is based on the projected growth of the data processing and communications equipment segments, in which most ASICs are used.

Six years ago, the ASIC market was dominated by US producers. Even so, of the top five ASIC suppliers in 1983, Fujitsu ranked as the leader, with slightly more than $100 million in sales, capturing slightly less than one-third of the total market. In 1989, however, three Japanese companies, Fujitsu, NEC, and Toshiba, with Fujitsu remaining the market leader, ranked in the top five, with LSI Logic and AMD positioned at third and fifth, respectively, rounding out the top five.

A large part of Japanese ASIC production is consumed by the supplier's parent company and therefore is not available to independent producers. However, the volume and experience gained through the resulting volume production for internal consumption will propel these companies into merchant market dominance.

Much debate occurs as to the relative merits of ASICs as a technology driver versus those of the traditional DRAMs. Dataquest believes that DRAMs remain the best vehicle for advancing the absolute limits of line geometry. Memory production provides the best "test pattern" for ensuring the highest levels of productivity and reliability in fab equipment. This relationship between memories, process manufacturability, and fab equipment is paramount in the development of new semiconductor technologies.

FERRAMs and Specialty Memories

Niche memory markets, such as those for FERRAMs or other specialty memories, are providing opportunities for small to medium-size companies. These markets are small, highly specialized, and require less capital investment to penetrate than their huge MOS DRAM/SRAM counterparts.

FERRAMs. FERRAMs are memory devices made from ferroelectric material that essentially merges the benefits of volatile and nonvolatile memory. Ferroelectric material allows the stored information to remain in storage when the power is removed. In volume production, such devices could be less expensive and faster than EEPROMs; their success could displace EEPROM demand.

Dataquest estimates that between 1992 and 1995, FERRAMs will have the potential to capture more than 50 percent of the demand for EEPROMs and therefore constitute a nearly $400 million market.

Specialty Memories. Specialty memories are a specific product category within the general memory segment that Dataquest defines as dual-port RAM, FIFO SRAM, and some other small-volume memory devices. The aggregate market for these memories—more than $103 million in 1989—is forecast to exceed $145 million in 1990 and $238 million by 1992. This growth represents a 1989 through 1992 CAGR of 32.2 percent, which is higher than that for the MOS memory segment as a whole—12.1 percent. Although these markets do not offer the tremendous sales volumes that more traditional memory products enjoy, they do offer significant niche market opportunities for the start-up semiconductor company.

Intelligent Power Devices

Intelligent power devices have been among the fastest-growing segments of the analog product category and have been produced mostly by US companies. Dataquest forecasts that the US benefits from this high-growth area may be short-lived, however, as the dominant consumers of analog and smart power devices increasingly are becoming consumer equipment producers. Because this equipment segment is dominated by Asia/ROW and Japanese equipment producers, Japanese companies that heretofore have stayed away from such analog products should be in a good position to enter this market successfully. Dataquest also notes that US analog producers have as of this date been markedly unsuccessful in selling to Japanese consumer electronics producers.

Microcomponents

The leadership in microprocessors, microperipherals, and microcontrollers always has belonged to the United States. However, at the low end of both the microcontroller and microprocessor segments, the Japanese producers are making strong inroads. For instance, the 8-bit microcontroller market, now dominated by the United States, is expected to fall to Japanese producers because of their expertise in CMOS volume manufacturing and their ability to develop a broad portfolio of specialized products.

In the 16- and 32-bit microprocessor arena, the United States is expected to remain dominant at the high-performance end of the spectrum. However, as the trend toward RISC architecture accelerates, opportunity presents itself for the Japanese to gain entry and position with a unique design.

The strongest semiconductor market position that the United States can claim is in this high-end, 32-bit MPU segment. It is critical to the US semiconductor and equipment industries that the United States retain its leadership in such proprietary developments, along with the associated peripheral and support devices.

Capital Spending and Access to Capital Funds

The battle for market share of the total semiconductor demand between regional companies has more importance than receiving a greater share of total revenue in any given year. For US companies that must operate in the highly unforgiving financial environment of the US investment community, market share is the fountainhead of reinvestment. Ultimately, access to investment capital to fund research and development and capital equipment for improving yields or expanding capacity is the lifeblood of long-term survival. Unfortunately, access to requisite investment capital depends more on stellar short-term profit performance in the eyes of the US investment community than on positioning for long-term growth and viability. A key question regarding the future of the US semiconductor industry is whether or not it can obtain the funds to keep up with Japanese capital spending. In dollar terms, the US companies have not kept up with the Japanese companies since the early 1980s. In yen terms, however, Japanese spending actually is at parity with the spending of US companies.

The Dataquest forecast for regional capital spending by region is shown in Table 6-15. The expected Japanese spending levels exceed those of the United States (in dollars) by almost 50 percent through the forecast period. Thus, Japanese companies had a larger 1989 base of semiconductor production capacity than US companies, and they are adding to that base at a faster pace.

Expenditure by the worldwide semiconductor producers on semiconductor equipment is represented by the capital spending forecast in Table 6-15. This becomes the total available market for the semiconductor manufacturing equipment producers. This demand and corresponding supply of semiconductor manufacturing equipment is the subject of the next chapter.

Avoidance of Government Intervention in Free Trade

The semiconductor production forecast assumes that the dollar exchange rates remain favorable for US exports of both electronic equipment and semiconductor devices. It further assumes that natural market forces will remain in effect and that historical trade barriers to Taiwanese, South Korean, and other Asian markets will be lowered. A critical assumption is that of a more favorable balance of trade between the United States and Japan. The objectives of the US-Japan Semiconductor Trade Arrangement of 1986—20 percent penetration of the Japanese market by US semiconductor producers—probably will take several years at its present rate to reach 20 percent share in Japan. In any case, more positive efforts to open the Japanese market must come forth to avoid US government intervention and the associated disruption of the natural market forces upon which the forecast is based.

Table 6-15

Worldwide Semiconductor Production
Regional Capital Spending—1988-1990
(Millions of Dollars)

	1988	1989	1990	Market Share 1988	Market Share 1990	CAGR 1988-1990
Worldwide Capital Spending						
US Companies	$3,339	$ 3,605	$ 3,677	35.8%	35.7%	4.9%
Japanese Companies	4,587	5,183	4,820	49.2	46.8	2.5%
European Companies	926	1,065	1,139	9.9	11.1	10.9%
ROW Companies	468	545	655	5.0	6.4	18.3%
Total Worldwide Spending	$9,320	$10,398	$10,291	100.0%	100.0%	5.1%
Annual Growth Rate	51.9%	11.6%	(1.0%)			
Capital Spending as Percent of Total Production	17.2%	17.5%	17.0%			

Note: Includes captive production
Source: Dataquest (August 1990)

CHAPTER 7

Semiconductor Equipment and Materials

Preceding chapters have discussed the electronics industry infrastructure in terms of a waterfall of demand. The waterfall starts with the demand for electronic equipment, continues with the demand for semiconductor devices, and ends with the demand for semiconductor equipment and materials (see Figure 7-1).

Semiconductor equipment manufacturers and semiconductor materials suppliers are positioned at the bottom tier of the waterfall, as they are the suppliers to the semiconductor manufacturers and the origin of the upstream flow of technology.

This upstream flow of technology creates the higher-performance and lower-cost semiconductor devices that result in superior electronic products. In fact, world leadership in the $653 billion electronic equipment industry requires world leadership in the $54 billion(merchant and captive) semiconductor industry, which in turn depends on world leadership in the relatively small $6 billion front-end equipment market. It is estimated that semiconductor materials represented approximately a $5 billion market in 1989; so together, equipment and materials accounted for over $11 billion.

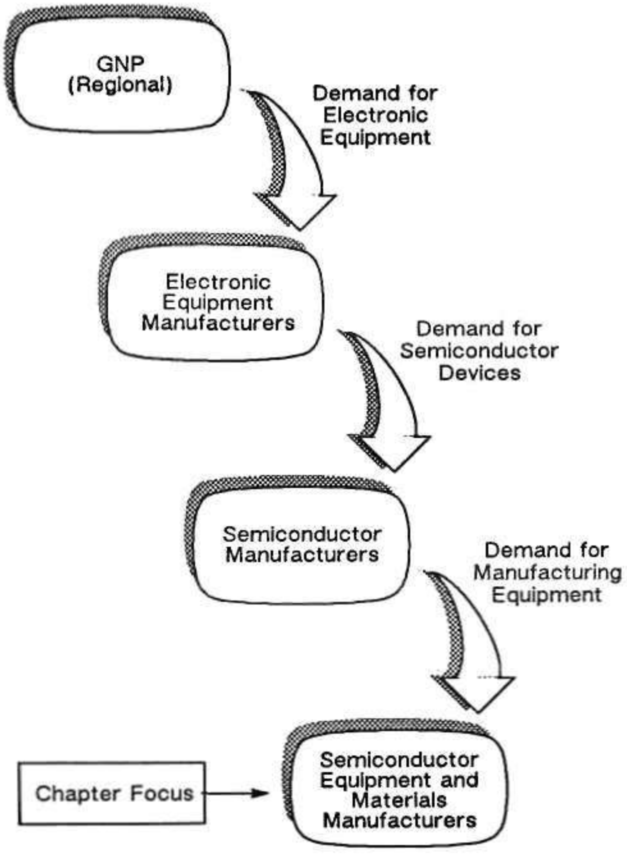
As the preceding chapters have stated, dependency on the source of technology that drives advancing functionality and lower-cost electronic products is so great that regional dominance of specific components of this relatively small industry virtually guarantees regional dominance of the upper tiers of the electronics industry infrastructure.

This chapter is organized into the following subsections:

- Background
  - Discussion of the underlying forces that have created demand for semiconductor equipment and materials
- Key semiconductor materials
- Semiconductor equipment
  - Semiconductor equipment product overview
  - Sources of semiconductor equipment demand
  - Semiconductor equipment demand history and forecast
  - Strategic issues facing the semiconductor equipment industry

Figure 7-1

Demand Waterfall



Source: Dataquest (August 1990)

Background—Semiconductor Equipment and Materials

Although semiconductor equipment and materials are grouped together in this subsection for discussion, it is important to note that semiconductor equipment demand reflects the capital spending budget of the semiconductor producer, while demand for materials is derived from manufacturing cost. Worldwide and regional demand for equipment thus is determined by the worldwide and regional needs for producers to either implement new technology or expand capacity. As a capital expense, such demand often is modulated by the producers' access to investment capital or the cost of such capital. Regional materials demand is more a function of pure semiconductor production levels within each region. In spite of the different budgets, expenditure, or demand for both equipment and materials within any given region, both depend on and contribute to the success and growth of the semiconductor producers within that region and worldwide.

As Chapter 6 pointed out, the success and growth of semiconductor producers within a region depends on the relative competitiveness of these producers and their corresponding ability to capture share of domestic semiconductor demand as well as that of other regions.

Key Semiconductor Materials

A variety of materials are used throughout the various processing steps of front-end wafer fabrication. These materials include wafer substrates such as silicon and gallium arsenide wafers, photoresist and its corresponding ancillary products, bulk and specialty gases, wet chemicals such as sulfuric acid and hydrogen peroxide, deionized water, metal-source targets for sputtering applications, dielectric coatings such as spin-on glass and polyimides, and liquid and solid dopant sources. This part of our discussion will focus briefly on the products, suppliers, and factors that characterize the markets of three of the key materials used in the manufacture of semiconductor devices: silicon wafers, photoresist, and semiconductor gases.

Silicon

Silicon is the second most abundant element in the earth's crust. It occurs in the form of oxides, or silicates such as silica (sand). In the 1950s, silicon was considered to be one of several materials with semiconductor potential. With the development of planar processing in 1960, polysilicon price reductions, and inexpensive plastic silicon transistor packaging, silicon superseded germanium in the market and today is the dominant substrate used in semiconductor device manufacture. As such, it is an excellent indicator of the level of manufacturing activity within a given wafer fabrication environment.

Products

Silicon wafers are thin slices of single-crystal silicon cut from a cylindrical ingot and then polished. The growth of a single-crystal ingot from polycrystalline silicon is controlled to produce wafers with a well-defined diameter, typically 3 to 8 inches.

A second category of silicon wafers is epitaxial wafers. Epitaxial processing produces a layer of single-crystal material that has the same crystallographic orientation as the underlying wafer substrate. It is possible to design the epitaxial layer to meet well-defined chemical, physical, and electrical specifications.

Dataquest estimates that the world merchant silicon and epitaxial wafer market was $2.3 billion in 1989.

Silicon Suppliers

Companies that produce silicon and epitaxial wafers are defined either as merchant silicon companies or captive silicon producers.

Merchant Silicon Companies. The vast majority of silicon consumed today is provided by merchant silicon suppliers. It is interesting to note that all major merchant silicon companies in the world today have large corporate parents. This provides a cash flow buffer against downturns in the business cycle, as well as a source of funding for new facilities and capacity expansions. In today's competitive business environment, it is unclear whether or not a standalone entrepreneurial silicon operation could compete and survive against the major silicon suppliers with their extensive financial backing from corporate parents.

Captive Silicon Producers. Silicon also is produced to a lesser extent by both merchant and captive semiconductor manufacturers. These semiconductor manufacturers are referred to collectively as captive silicon producers because they grow single-crystal silicon to produce wafers for their own internal consumption.

Semiconductor manufacturers with captive silicon production tend to be established, vertically integrated companies. In the early years of the semiconductor industry, the high cost of silicon provided sufficient economic justification for some semiconductor manufacturers to develop this internal capability. Today, however, high-quality, low-cost silicon wafers are readily available from a number of merchant silicon companies. Nevertheless, one benefit of retaining captive silicon production activities is that a semiconductor company can manufacture wafers with custom and proprietary specifications. In addition, captive silicon producers in the United States can ship silicon material to their facilities in Japan and Europe, thereby avoiding those regions' relatively higher wafer costs resulting from currency appreciation over the last several years.

Factors that Characterize the Silicon Wafer Industry

Two significant factors characterize the silicon wafer industry of the last several years. These factors are wafer pricing pressures and industry consolidation.

Wafer Pricing Pressures. Dataquest believes that wafer pricing pressure has been one of the major factors that has affected profitability in the silicon industry during the last several years. Historically, as large wafer products mature, prices decrease because silicon wafer companies move down the learning curve of wafer manufacturing. Pricing has been an important competitive issue as well.

During the downturn of the business cycle between 1985 and 1987, however, there were additional pressures from cost-conscious semiconductor manufacturers for lower prices. At the same time, increasing device complexity led to demands for tighter wafer specifications. This, in turn, meant that silicon companies have had to perform more analytical tests to ensure wafer quality. More analytical testing and product qualification mean higher costs to the silicon companies, and, with the continued downward pricing pressures, silicon companies have been forced to accept smaller margins on their products.

During the healthy market environment of 1988, merchant silicon companies experienced some relief from the downward pricing pressures of previous years. This trend has allowed some silicon companies to return to profitability after several years of losses. Dataquest believes that a favorable and stable wafer pricing environment is essential in order to avoid severe profitability problems in the silicon wafer industry in the future.

Industry Consolidation. A series of eight acquisitions of merchant silicon and epitaxial wafer companies has occurred since 1985 (see Table 7-1). In the majority of these acquisitions, the new corporate parent was already active in the silicon wafer industry prior to its acquisition of its new silicon company. These acquisitions illustrate the dynamics of consolidation in a maturing industry.

As seen in Table 7-1, seven of the eight acquisitions consisted of US silicon companies being acquired by Japanese or West German corporations. The two most recent acquisitions, in particular, had a significant impact on the worldwide market share of US-based silicon suppliers by reducing their share to less than 1 percent of the worldwide merchant silicon market. This situation has raised several important concerns. With the United States' loss of all control over the production of merchant silicon wafers, are its semiconductor manufacturers at a disadvantage in the development of next-generation integrated circuits? Will silicon operations under foreign ownership be fully responsive to the needs of US semiconductor manufacturers?

Clearly, other countries already have decided that silicon is a crucial strategic material. Most of the new entrants in the merchant silicon wafer market over the last several years have come from outside the United States—notably from Japan, Europe, and the Pacific Rim. In these countries, the short-term rigors of the silicon wafer market are endured as part of a long-term strategy for survival in the electronics industry.

Photoresist

Photoresist is a light-sensitive, polymer-based material applied to wafers during semiconductor fabrication to transfer the circuit pattern from a mask to the underlying substrate. Photoresist is applied to the wafer at every mask level during the fabrication process; the number of mask levels correlates with device complexity.

Table 7-1

Recent Acquisitions in the Silicon Wafer Industry

Acquisition Announced	Company	Acquired By
1990	Union Carbide Polysilicon (US)	Komatsu Electronic Metals (Japan)
1989	IBM Silicon Wafer Operation (US)	Huels/MEMC (West Germany
1988	Monsanto Electronic Materials Company (US)	Huels AG (West Germany)
1988	Cincinnati Milacron (US)	Osaka Titanium Co. (Japan)
1987	Dynamit Nobel Silicon (Italy)	Huels AG (West Germany)
1986	US Semiconductor (US)	Osaka Titanium Co. (Japan)
1986	Siltec Corporation (US)	Mitsubishi Metal (Japan)
1985	NBK Corporation (US)	Kawasaki Steel (Japan)

Source: Dataquest (August 1990)

Products

Resists used in semiconductor device fabrication typically are classified into four different categories that reflect the sensitivity of the resist to a given type of light or radiation. The four categories are optical, deep-UV, e-beam, and X-ray resists.

Resists are characterized as positive- or negative-working materials. The basic difference between a positive and a negative resist depends on the material's response to light or radiation. A positive resist leaves behind an image on the wafer that matches the pattern on a mask, while a negative resist leaves behind an image that is the reverse of the mask pattern.

In addition to the resist material itself, there is an associated class of chemicals known as resist ancillary products. These include developers, rinses, dyes, strippers, thinners, adhesion promoters, and etchants. The developers, in particular, are closely designed to complement a given resist formulation in order to optimize resist performance.

Almost all resist materials used in semiconductor device fabrication today are optical photoresists. Dataquest estimates that the 1989 world market for optical photoresist was approximately $265 million.

Photoresist Suppliers

Typically, photoresist companies are part of larger chemical or electronic materials corporations. Four major companies dominate the world's optical photoresist market today: One is Japan-based, two are US-based, and one is Europe-based. The major Japanese photoresist supplier historically has focused on its home market of Japan. In contrast, the two major US suppliers and the major European photoresist company have a well-established presence in all three of the major processing regions of the world: Japan, the United States, and Europe. This has been achieved through overseas photoresist operations (including manufacturing plants) and joint ventures.

Export Market Strategies. Dataquest has observed that when Japanese semiconductor manufacturers set up new fab facilities outside of Japan, often these new fabs are designed to duplicate an existing line in Japan. These include not only products and process technology, but also fabrication equipment and semiconductor materials. This strategy allows the semiconductor manufacturer to bring the new fab line up to speed in a very short period of time.

This practice has particular significance for Japanese photoresist suppliers, which historically have had only minimal participation in export markets such as the United States or Europe. Because photoresist is such a complex chemical system, Dataquest believes that it will be a high priority with Japanese semiconductor manufacturers to use the same resist for their new fab facilities outside of Japan as in their current fabs in Japan. Therefore, Japanese resist companies now have a well-defined avenue to expand their export market opportunities.

Factors that Characterize the Photoresist Industry

Several factors and issues characterize today's photoresist industry, including the following:

- Photoresist is closely tied to lithography, the technology driver for manufacturing higher-density integrated circuits.
  - As semiconductor manufacturers continue to push the limits of submicron processing, it is clear that the lithography process must be considered as a single system. This system includes the device process technology, the lithography equipment, lenses, and sources, as well as the photoresist material itself.
  - Dataquest believes that joint development and exchange programs between semiconductor companies, equipment vendors, and photoresist manufacturers will be essential in the development of advanced submicron processes.
- One of the major issues facing semiconductor manufacturers today is to determine what strategy will be adopted for 0.5-micron device processing expected in production in the mid-1990s.
  - Currently, several lithography alternatives exist including g-line steppers, i-line steppers, excimer laser steppers, step-and-scan lithography, or X-ray lithography. Right now, however, there is no clear consensus of opinion.
  - For photoresist manufacturers, this also is a key issue because few companies have sufficient R&D funds to develop new resist formulations for all lithographic alternatives. Photoresist companies today are faced with deciding where to focus their R&D efforts, ever mindful that different regional semiconductor manufacturers may well pursue different lithography strategies.
- Photoresist is perceived by the customer to be a technology-driven product because the material's performance is closely tied to lithography processing.
  - Therefore, photoresist suppliers have not experienced the same level of downward pricing pressure as in other electronic material categories.
  - Pricing—for optical positive resist, in particular—has remained fairly stable or experienced a modest increase as new resist formulations are developed for the processing of smaller line geometries.

Semiconductor Gases

Products

Semiconductor gases generally are divided into two product categories: bulk and specialty gases.

Bulk Gases. The bulk semiconductor gases are nitrogen, oxygen, hydrogen, and argon. The "bulk" designation typically refers to a discrete delivery of a large volume of gas by truck transport. These gases typically are delivered as cryogenic liquids because of the efficiency of transportation and storage prior to the vaporization stage at the semiconductor manufacturer's facility. In addition to cryogenic liquid delivery, nitrogen gas also is provided through direct pipeline delivery, as well as at customer on-site nitrogen-generation plants.

Specialty Gases. A large number of gases (more than 35) are classified as semiconductor specialty gases. For that reason, a further segmentation of this category is necessary and is based on the chemical reactivity and functionality of the various specialty gases. Dataquest segments the specialty gas market into six categories: silicon-precursor gases, dopants, etchant gases, reactant gases, atmospheric/purge cylinder gases, and others. Specialty gases are used in comparatively smaller volumes than bulk gases; thus, they are delivered in high-pressure cylinders.

Dataquest estimates that the 1989 world market for semiconductor bulk and specialty gases was approximately $705 million.

Semiconductor Gas Suppliers

Several factors will dictate the success of a gas company supplying the semiconductor industry. These include an extensive distribution network, some level of primary manufacturing capability, and a strong service organization.

Five companies and their associated operations dominate the world's semiconductor gas industry today. These major suppliers of semiconductor gases have a good-to-strong presence in the four major semiconductor production regions of the world: Japan, the United States, Europe, and the Pacific Rim. This presence is achieved through overseas operations, equity investment positions in foreign gas companies, or technical/marketing agreements.

For the major gas suppliers, the semiconductor gas market represents only a small portion of a company's total gas business activities. Some of the nonsemiconductor gas applications that represent far larger market opportunities include nitrogen for frozen food processing, oxygen for steel processing, and hydrogen for fuel cells in the rocket and aerospace industries. However, the semiconductor industry represents probably the most rigorous demands on gas suppliers with regard to providing high-purity materials and delivery systems. Therefore, success in the semiconductor gas industry promotes a gas supplier's presence at the cutting edge of gas technology.

Factors that Characterize the Semiconductor Gas Industry

Several unique factors characterize the semiconductor gas market, including the following:

- The specialty gas companies are unique when compared with other electronic materials companies that sell products to the semiconductor industry. What makes this market different is that no one specialty gas company has primary manufacturing capability for all of the specialty gases that it provides to the industry. Thus, a specialty gas company typically must buy some of its products from a competitor.

- Nitrogen is consumed by the semiconductor industry in substantially larger volumes than any other gas and accounts for approximately 80 percent of semiconductor bulk gas sales. While bulk and specialty gas usage typically tracks with semiconductor device production levels and the consumption of silicon wafers, nitrogen also is used to maintain the integrity of processing equipment whether wafers are being processed or not. This means that the nitrogen market, unlike other electronic materials, is very stable even during the times of low production associated with downturns in the semiconductor business cycle.

- The semiconductor bulk gas industry is characterized by long-term contracts between vendor and customer because of the support equipment required at the customer's site for the on-site storage of bulk gases. Typically, one bulk gas supplier supports each fab facility, and that company often will receive the initial gas contract before construction even begins on a new fab. In contrast, the specialty gas industry is characterized by short-term contracts and an ongoing competitive market environment. Multiple specialty gas vendors per fab is the norm rather than the exception.

Background—Semiconductor Equipment

Initially, in the 1950s and 1960s, because there was no commercial source for semiconductor equipment, such equipment was built for internal use by semiconductor producers such as AT&T, IBM, Motorola, and Texas Instruments. In the late 1960s and 1970s, merchant semiconductor equipment manufacturers began to provide equipment to world semiconductor producers. In the beginning, most of the companies were of US origin, with the Japanese and European equipment manufacturers following somewhat later. Major semiconductor companies began to depend on merchant semiconductor equipment suppliers, and equipment that was internally supplied by semiconductor producers began to decline. Thus, the merchant semiconductor equipment industry is approximately 20 years old, and it is interesting to note that several of the world's major equipment manufacturers celebrated their 20-year anniversaries in 1988.

The demand for semiconductor equipment in Japan was fueled by the rise of the Japanese semiconductor industry in the early 1970s, and this demand was met by two sources. The first was the rise of the indigenous Japanese equipment industry, and the second was the transfer of equipment technology to Japan from the United States. US equipment manufacturers, in an effort to penetrate the fast-growing Japanese equipment market, provided Japanese equipment manufacturers access to US-developed technology. By the late 1970s and early 1980s, Japanese equipment companies emerged as merchant suppliers, providing crucial technologies for new VLSI devices manufactured by the fast-growing Japanese semiconductor companies. In 1989, Japanese wafer fab equipment companies shared five of the top ten places in the ranking of worldwide wafer fab equipment suppliers. In terms of world market share for wafer fab equipment, Japanese equipment companies have taken the lead in total market share over US equipment suppliers. In certain equipment categories (for instance, lithography) Japanese equipment makers clearly dominate the world market.

Semiconductor Manufacturing Equipment—Product Overview

The equipment used for the production of semiconductor devices is divided into two major segments: wafer fabrication (front end) equipment and assembly and test (back end) equipment.

Wafer fab equipment is the very sophisticated capital equipment used to manufacture IC devices on the silicon wafer. Front-end, or wafer fab, equipment includes those crucial technologies required for manufacturing critical VLSI devices such as 4Mb and 16Mb DRAMs, 32-bit and larger microprocessors, and advanced logic devices.

IC manufacture, or the wafer fabrication process, takes place in a special ultraclean facility called the fab or clean room. Bare silicon wafers are the input material to the wafer fab; finished silicon wafers are the output of the fab. In many cases, each wafer contains hundreds of manufactured ICs.

The finished wafer then is sent to the assembly and test facility, where the wafer is cut up into individual ICs. The good ICs are separated from the bad; the good ICs are then assembled and packaged and each packaged IC tested. Generally, the wafer fabrication facility and the assembly and test facility are separate; in many cases, the latter facility may be located in another country.

Technical advances in wafer fab equipment directly affect advances in manufacturing ICs. This means that more sophisticated ICs with more functionality or higher speeds or both can be manufactured. As more sophisticated ICs become available, more advanced electronic equipment becomes available, forging a direct link between wafer fab equipment and advanced computers and telecommunications equipment. Thus, technology leadership in the relatively small $5.9 billion worldwide wafer fab equipment market is the gateway to leadership in the $653 billion worldwide electronic equipment market. In addition, the semiconductor company that uses the latest wafer fab equipment will have a competitive advantage in the IC market.

As more sophisticated ICs are manufactured, more sophisticated assembly and test equipment must be developed; in conjunction with the advances in equipment, advances must be made in semiconductor materials as well. However, the driving force in semiconductor manufacturing is wafer fabequipment, or the ability to manufacture the advanced IC itself. This is the area that tends to drive advances in materials as well as in assembly and test equipment. For this reason, the remainder of this chapter will focus on wafer fab equipment. This is not to minimize the strategic importance of semiconductor materials and assembly and test equipment, but rather to recognize that technology leadership in wafer fab equipment is more closely linked with leadership in the huge electronic equipment market.

Of the total amount of capital spending by the world's semiconductor manufacturers, approximately 80 percent is spent on front-end and back-end equipment; of this amount, 60 percent is spent on wafer fab equipment. Thus, wafer fab equipment represents approximately 50 percent of the spending by the world's semiconductor producers and reached almost $6 billion in 1989.

Wafer fabrication equipment is divided into 11 major categories, 8 of which are briefly described in the following paragraphs. This equipment is used to perform the approximately 400 steps required to make an advanced IC. In its simplest description, the IC wafer fabrication process can be divided into three basic operations: thin films are deposited on the silicon wafer, the deposited films are patterned, and the film characteristics are altered.

Lithography

If wafer fab equipment is the driving area for IC production, lithography is the very heart and core of advanced IC manufacturing technology. Lithography is the engine that drives all other technologies used in IC manufacturing. It is the critical patterning technology for VLSI devices because it is the technology enabler for fine-line geometries. The term fine-line geometry refers to the minimum geometries of semiconductor devices. The finer the geometry, the more transistors the IC designer can put on a chip or the more functionality the chip has. For instance, a 1Mb DRAM, which has more than 1 million transistors on the chip, is fabricated with minimum feature sizes of approximately 1.2 micron (the diameter of a human hair is 100.0 microns). Advances in lithography tools now allow 0.8-micron feature sizes to be produced on the chip. With this finer feature size, 4Mb DRAMs containing more than 4 million transistors can be produced. Currently, advanced lithography tools can pattern lines as small as the 0.5-micron feature sizes required for 16Mb DRAMs. Finer geometries also mean that faster chips can be produced, which are essential for building ever-faster computers.

Lithography equipment includes contact and proximity aligners, scanning projection aligners, steppers (reduction and 1:1), e-beam systems, X-ray aligners, and the recently announced step-and-scan aligner, each of which is described briefly as follows:

- Contact/proximity aligners—the industry's first lithography tools, which reach back to the very beginnings of the semiconductor industry—have declined. Today, they are a $20 million niche market. This product is not likely to play a major role in the future lithography market.

- Scanning projection aligners superseded contact/proximity aligners to become the dominant lithography tool for many years. However, this tool is limited in its ability to pattern fine features, and it eventually gave way to steppers.

  - Projection aligners reached their peak in 1984 and 1985 and have since declined to a $94 million market in 1989, representing only 6.5 percent of the total world lithography market of $1,453 million.

  - More than 3,000 of these aligners are in the field, and this base of aligners will continue to grow slowly to provide additional capacity in existing fabs. However, the newer advanced fabs are not being outfitted with scanning projection aligners.

- Steppers, because of their inherent ability to pattern finer features than scanning projection aligners, have become the dominant and state-of-art lithography tool.

  - In 1989, steppers accounted for $1,191 million, or 82 percent, of the total lithography market. Steppers probably will continue to dominate the lithography market for several years.

  - Today, all advanced ICs are fabricated using steppers, and production-worthy steppers in the most advanced fabs can pattern 0.7-micron features. Advanced excimer laser steppers that can pattern 0.35-micron features are under development.

  - Steppers have a solid technology grasp on the lithography market, but it could be weakened by the recent advent of the step-and-scan aligner.

- The potential of the step-and-scan aligner, which was recently introduced to the marketplace, is still uncertain.

  - If successful, step-and-scan systems could compete with steppers and erode their market share.

  - This aligner is a hybrid system that combines the best of both scanning projection technology and stepper technology. It currently appears to be the most advanced aligner on the market, but because it is a new system, field experience is not yet available.

  - This aligner can pattern 0.5-micron features with a wafer throughput that excels steppers, and it is the dark horse in the lithography race.

- E-beam lithography systems have two niche applications.

  - E-beam is the technology used by the worldwide maskmaking industry to produce the masks and reticles required by semiconductor manufacturers for their projection aligners and steppers.

  - E-beam also is used to "direct write" a wafer in special instances, such as quick-turn IC prototyping and small quantity ASIC devices.

  - Together, these two niche markets accounted for $143 million of the 1989 lithography market. However, because of its very low productivity and high cost per wafer, e-beam is not likely to be a mainstream lithography technology, although it can pattern finer geometries than steppers.

- The world semiconductor manufacturers have essentially ignored X-ray aligners (the 1989 market was $5 million) in spite of the numerous advantages of X-ray aligners over conventional optical aligners such as steppers.
  - The semiconductor industry is very slow to accept new technologies, and because the stepper manufacturers continue to make advances in stepper technology, the market window for X-ray aligners continues to be pushed out.
  - Currently, there are X-ray aligners on the market that can pattern 0.5-micron features and less. These aligners are standalone systems and resemble conventional steppers; it is uncertain just how much less than 0.5-micron they can be used in a production environment.
  - However, considerable worldwide development is under way on another type of X-ray technology called synchrotron orbital radiation (SOR) that will have a production limit of approximately 0.2 micron.
    - The Japanese are making very heavy investments in this technology.
    - In addition, IBM already has invested $500 million in SOR and expects to spend $1 billion by the time the system is fully developed.

In summary, steppers are the dominant tool today and will continue to be the dominant tool until the industry reaches 0.5-micron feature sizes, probably by the mid-1990s. At that point there are several competing technologies, and currently it is not clear which technology will be dominant. The dominant technology may very well continue to be steppers, but we must wait for further developments before reaching more secure predictive ground.

Automatic Photoresist Processing Equipment

Automatic photoresist processing equipment, or track equipment as it is commonly known, is used to apply and process the photoresist film that is temporarily applied to the wafer to allow patterning of the wafers by the lithography equipment. The main technical objectives of track systems are to deposit the thin photoresist coatings prior to the patterning process that takes place in the lithography tool and to develop the photoresist after patterning.

Track equipment includes wafer clean/bake, wafer prime, coat/bake, develop/bake, and photoresist stabilization equipment. Track equipment is used in the lithography cell of the wafer fab and actually can be considered part of the lithography process. Because of this, the demand for track systems is closely tied to lithography demand and has about the same compound annual growth rate (CAGR). In 1989, the demand for track equipment reached $325 million.

Etch and Clean

This segment includes wet process, dry etch, dry strip, and ion milling equipment. Wet processing, so-called because ultrapure water and liquid chemicals are used in the process, is used throughout the wafer fab for the cleaning and wet etching of wafers. Wet processing goes back to the early days of the semiconductor industry. Etching, along with lithography and track equipment, is another of the equipment technologies that is part of patterning thin films on the wafer.

Wet etching is used for patterning relatively large features on the wafer, while dry etching, the newer technology, is used almost exclusively in the fabrication of advanced devices that require fine-feature patterning. As advances in lithography equipment allow finer features to be patterned on the wafer, concomitant advances in dry-etch equipment need to be made to fully implement the fine-pattern features on the wafer.

Dry-strip equipment is used to remove the photoresist films that are temporarily applied to the wafer to allow patterning. The total etch-and-clean market was $1,066 million, of which $306 million was for wet-process equipment, $636 million was for dry-etch equipment, and $116 million was for dry-strip equipment.

Deposition

Deposition includes several technologies that are used to deposit thin films on the wafer. The three major technologies included in this category are chemical vapor deposition (CVD), physical vapor deposition (PVD), and epitaxy. Epitaxy technology includes silicon epitaxy, metalorganic CVD, and molecular beam epitaxy equipment. Once these films are deposited by any of three major techniques, they are patterned with the aid of the lithography, track, and etch equipment previously described.

CVD equipment generally is used to deposit insulator films on the wafer, while PVD is used to deposit the aluminum films that are required to wire-up, or connect, all of the transistors on a chip (more than 4 million transistors are used, for example, in the case of 4Mb DRAMs). Collectively, CVD and PVD equipment is used to fabricate the interconnect portion of the chip. As with advances in lithography, advances in CVD and PVD equipment need to be made in order to keep up with current technologies. When new advanced steppers are introduced that have ever-smaller fine-pattern capability, it sets off a new round of development in CVD and PVD equipment (as well as in other front-end equipment); CVD and PVD manufacturers then must struggle to keep pace. For instance, the equipment and technology required to interconnect the more than 4 million transistors of a 4Mb DRAM are vastly more sophisticated (and costly) than was required for the 65,000 transistors of a 64K DRAM of a few years ago. In the past, the portion of chip fabrication cost that was attributed to chip interconnection was small. With advanced chips that have several levels of interconnection on the chip, the cost of interconnection can be 50 percent or more of the entire wafer fabrication cost.

In 1989, the total deposition market was $1,145 million; CVD accounted for $580 million of this market, PVD for $377 million, and total epitaxy for the remaining $189 million. There is currently a tremendous amount of activity in both the CVD and PVD technology areas as new equipment is being introduced to fabricate the most advanced ICs.

In PVD equipment, attention is being directed toward integrated processing systems that will be able to handle several process steps in one piece of equipment instead of having to move the wafer to several pieces of equipment to accomplish the same number of process steps. Generally, as advance chips need to be manufactured, the semiconductor industry will move to more integrated manufacturing. This eliminates human handling of the wafers, decreases contamination, and increases yields.

We said previously that lithography essentially drives the other technologies used in the fabrication of a wafer. Although lithography tools are well on the path to fine-line patterning, work still needs to be done in the deposition of thin films, either by CVD or PVD.

Diffusion Furnaces

Diffusion furnace equipment includes both horizontal and vertical tube furnaces. These high-temperature furnaces are used to incorporate precise quantities of impurities, or dopants, into the deposited films on the wafer in order to control the electrical properties and, hence, the performance of the IC. Other applications include the growing of oxide films, the deposition of insulator films, and annealing.

Horizontal tube furnaces, the workhorses of the industry since their inception, have been losing ground to other technologies such as ion implantation and CVD equipment. For advanced devices, ion implantation now is the preferred method of introducing impurities into the wafer, and CVD is the preferred technology for film deposition. Although the number of horizontal furnaces has declined substantially since the technology's peak a few years ago, ASPs have risen to the extent that horizontal furnace sales reached a record $327 million in 1989.

Vertical furnaces are an emerging technology. Vertical furnaces have several advantages over horizontal furnaces, particularly for advanced devices, and they are being rapidly accepted in Japan. Some advantages include lower power consumption, smaller space requirements, easier automation, and excellent technical performance. In the past, only horizontal furnaces were used in the fab, but Japan expects vertical furnaces to be the dominate furnace technology of the future. In other regions of the world, vertical furnaces have been given a lukewarm reception. Vertical diffusion furnace sales were $90 million in 1989.

Rapid Thermal Processing

Rapid thermal processing (RTP) is a high-temperature technology that was expected to supplant the annealing process of diffusion furnaces. However, this equipment has not found its way into the production mainstream of the wafer fab for this application because anneals done on diffusion furnaces are superior to RTP anneals. RTP is beginning to find opportunities in other applications in the wafer fab, such as in the thin-film area, but these are still emerging. In 1989, the RTP market amounted to $28 million.

Ion Implantation

In the past, introduction of impurities into the thin films on the IC was done in diffusion furnaces, but diffusion furnaces are inadequate for advanced devices that have fine features. Ion implanters provide a much more precise control of the amount, location, and depth of the impurity into the thin film. Implanters are classified as medium current or high current, depending on the amount of impurity that can be incorporated quickly into the film. High-voltage implanters also can incorporate impurities to a greater depth in the film than can either medium- or high-current implanters. It is interesting to note that implanters are essentially linear accelerators and have their roots in that technology. In 1989, the total world market for implanters was $468 million.

Diffusion furnaces, rapid thermal processing equipment, and ion implanters all are used in the wafer fabrication process essentially to modify the thin films that were deposited and patterned by the other equipment technologies described previously.

Critical Dimension/Wafer Inspection

Critical dimension (CD) and wafer inspection equipment are two types of process control equipment. Process control equipment is used to verify the wafer fabrication process rather than contribute to the actual fabrication of the IC. CD equipment is used to measure the features on the wafer to ensure that the patterning process is indeed doing what it is supposed to do. Wafer inspection equipment is used to check for defects on the wafer. Both CD and wafer inspection equipment have a tremendously wide variance in price, depending on the level and sophistication of operator automation. Systems may range from $50,000 for a low-end manual system to $1.2 million for a fully automated advanced system.

CD and wafer inspection equipment technology also is driven by advances in lithography. As finer and finer features are fabricated on the IC, it becomes necessary to measure smaller and smaller features with greater accuracy and precision. Also, as feature sizes get smaller, it becomes necessary to check for ever-smaller defects, and to identify new types of defects. In 1989, the combined markets for CD and wafer inspection equipment totaled $187 million.

Sources of Semiconductor Equipment Demand

The two fundamental sources of demand for semiconductor production equipment are as follows:

- Semiconductor producers purchase advanced equipment to increase competitiveness by decreasing manufacturing cost through advanced manufacturing technology.
- Semiconductor producers purchase equipment to expand production capacity.

Advanced Manufacturing Technology Increases Competitiveness

The primary driving force for new semiconductor equipment for the next two to three years will be the need for advanced manufacturing technology. As mentioned previously and discussed fully in Chapter 6, the success and growth of semiconductor producers within a given region depend ultimately on their relative competitiveness. This competitiveness is determined by regional economic factors such as cost of labor, cost of capital, and availability of patient capital, but it ultimately is reduced to relative product quality and manufacturing costs.

Thus, relative competitiveness depends on the following:

- Efficiency—Higher yields provide lower cost per device.
- Fast turnaround—The earlier a producer gets to market and moves down the learning curve, the more costs become lower and remain lower than those of competitors that enter the market later.
- Higher quality and reliability—The quality and reliability of devices are more important to the device user than the absolute price.

Semiconductor equipment demand based on upgrading competitiveness through manufacturing technology therefore is driven by these factors. Key manufacturing technologies that contribute to these factors are those that contribute to smaller feature sizes, higher productivity, and reduced contamination. Smaller feature sizes provide increased functions per die, higher speeds, and increased die per wafer. Higher productivity translates into more ICs manufactured per time period, and reduced contamination contributes to higher yields, or more good die per manufacturing run.

Another key manufacturing parameter is turnaround, or cycle time, which is the length of time it takes to fabricate a wafer. A producer with shorter cycle times than its competitor moves down the learning curve faster because it is able to correct the IC fabrication process when necessary in a shorter interval of time. As the producer moves down the learning curve, its manufacturing costs decline with a concomitant competitive advantage. Therefore, the key technology demand drivers for manufacturing equipment are all related to the front-end process. Table 7-2 shows the worldwide wafer fab market for 1989 by equipment segment.

Table 7-2

1989 Worldwide Wafer Fab Equipment Demand (Millions of Dollars)

Equipment	Demand
Lithography	
Contact/proximity	20
Projection aligners	94
Steppers	1,191
Direct-write e-beam	70
Maskmaking e-beam/laser	73
X-ray	5
Total Lithography	1,453
Automatic Photoresist Processing Equipment	325
Etch and Clean	
Wet process	306
Dry strip	116
Dry etch	636
Ion milling	9
Total Etch and Clean	1,066
Deposition	
Chemical vapor deposition	580
Physical vapor deposition	377
Silicon epitaxy	72
Metalorganic CVD	44
Molecular beam epitaxy	73
Total Deposition	1,145
Diffusion	327
Rapid Thermal Processing	28
Ion Implantation	468
CD/Wafer Inspection	187
Other Process Control	485
Factory Automation	195
Other Wafer Fab Equipment	206
Total Wafer Fab Equipment	5,887

Note: Columns do not add to totals shown because of rounding.
Source: Dataquest (August 1990)

Capacity Utilization Drives Capacity Expansion

The second driving force behind equipment demand is the requirement to increase production capacity. As regional producers realize success and growth through superior relative competitiveness, they use up existing production capacity and must invest in capacity expansion. Therefore, not only does the semiconductor equipment supplier contribute to the growth and success of the semiconductor producer by improving competitiveness, the producer's success fuels the growth and success of the supplier as well.

Figure 7-2 presents regional capacity utilization by regional company base for North America, Europe, and Japan. Table 7-3 compares historical worldwide merchant semiconductor production with worldwide capital spending and wafer fab equipment demand.

In a time of rapidly expanding demand for semiconductors, the demand for equipment surges. This is illustrated by the boom period of 1983 and 1984, as producers in all regions eagerly expanded capacity in response to the buoyant PC-driven semiconductor demand forecast. This resulted in a capacity utilization and equipment demand peak in 1984. The subsequent collapse of semiconductor demand in the following two years resulted in a severe downturn of equipment demand as capacity utilization plummeted.

The strong recovery of semiconductor demand from 1987 through the present has generated higher demand for production equipment. Table 7-3 shows that the worldwide demand for semiconductor front-end equipment has increased 20 percent in 1989 over 1988. However, as the next paragraphs will show, most of this growth in equipment demand in the 1987 through 1989 period was for competitiveness improvement rather than capacity expansion, because only now are utilization rates beginning to exceed those of the boom years. Table 7-3 also illustrates that 49 percent of the total capital spending by semiconductor manufacturers is spent on wafer fab equipment. Dataquest estimates that the balance of the spending goes to purchase back-end equipment (31 percent) and property and facilities (20 percent).

Table 7-3

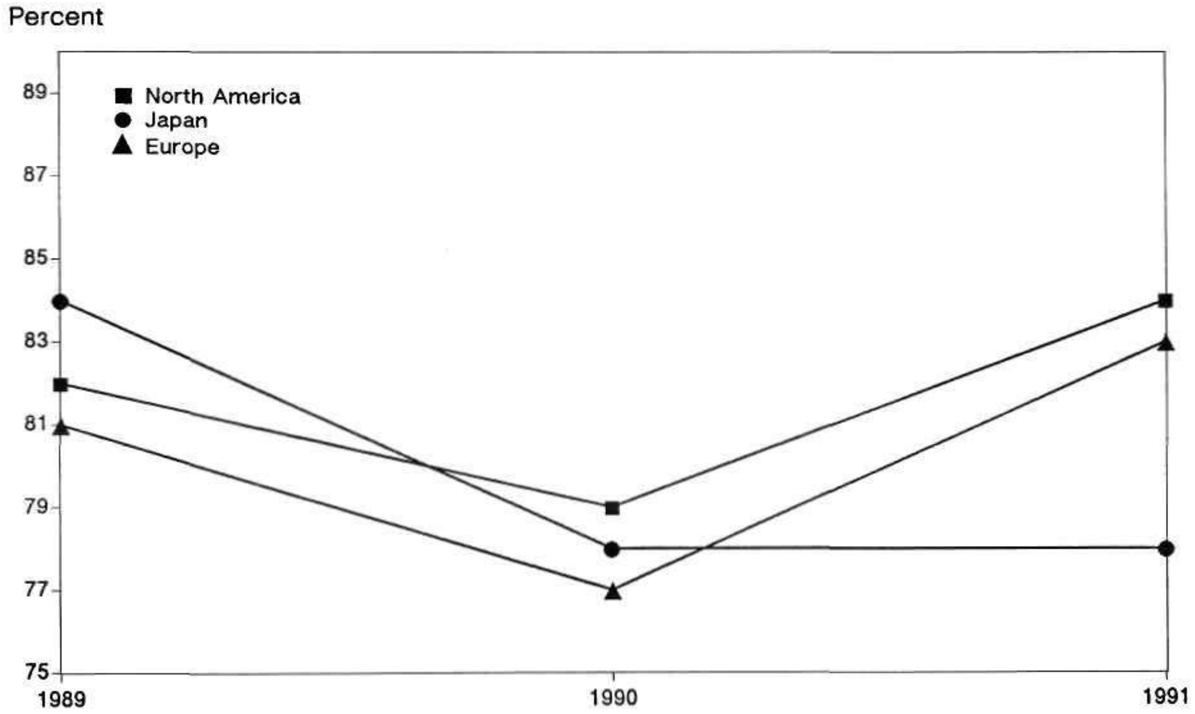
Worldwide Electronic Equipment and Semiconductor Consumption
1988-1989
(Includes Captive Suppliers)

	1988	1989
Electronic Equipment Production	$618.1	$653.1
Semiconductor Production	$ 54.5	$ 59.9
Capital Spending ($B)	$ 10.0	$ 12.2
Capital Spending Annual Growth	56.8%	21.4%
% of Production	18.3%	20.2%
Front-End Equipment Demand ($B)	$ 4.9	$ 5.9
% of Capital Spending	49.0%	48.4%
Annual Growth of Equipment Demand	58.2%	20.3%

Source: Dataquest (August 1990)

Figure 7-2

Estimated Regional Semiconductor Capacity Utilization
1989-1991



Source: Dataquest (August 1990)

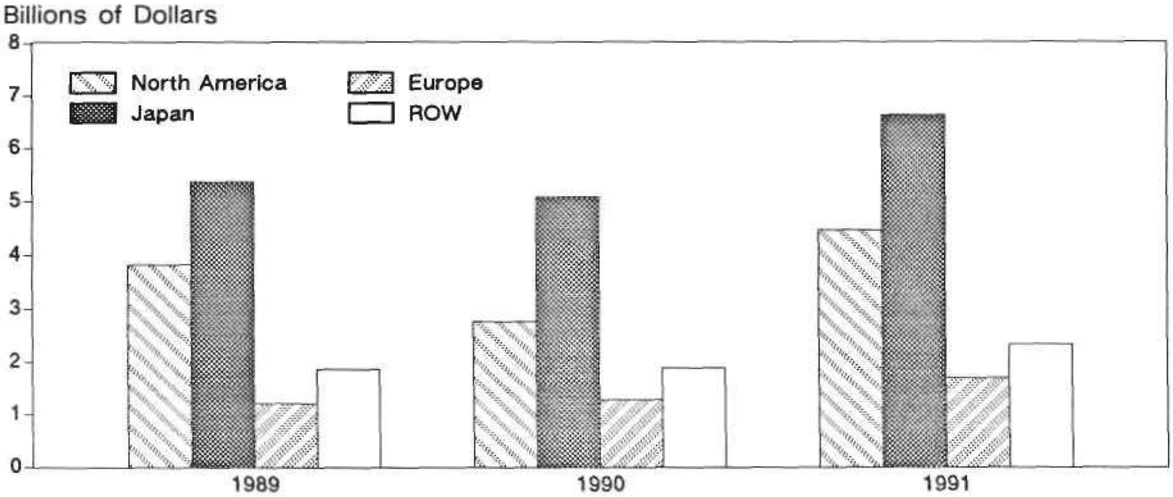
Regional Demand History 1984 to 1989

Figure 7-3 illustrates the regional capital spending of merchant and captive producers regardless of nationality. This represents the regional total available market for goods purchased from such capital expenditure.

Figure 7-4 compares the capital spending in just Japan and North America for the period 1989-1991. In 1984 and 1985, spending in Japan was significantly higher than in North America. However, in 1986 and 1987, capital spending in Japan was slightly less than capital spending in North America. In 1988, the Japanese market for capital equipment underwent a strong comeback

Figure 7-3

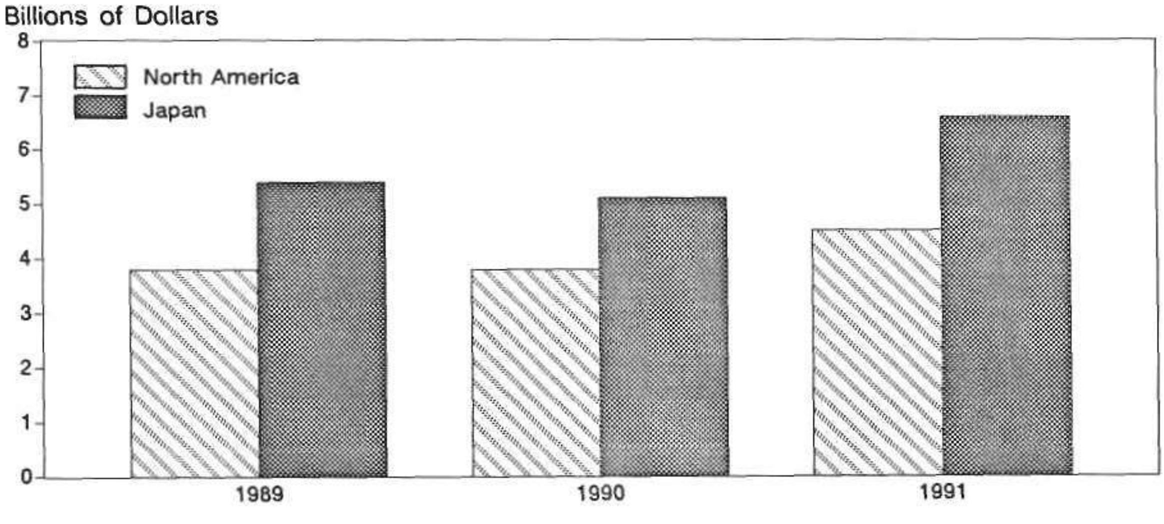
Worldwide Capital Spending Forecast Regardless of Company Regional Base 1989-1991



Source: Dataquest (August 1990)

Figure 7-4

Estimated Regional Semiconductor Capital Spending 1989-1991



Source: Dataquest (August 1990)

and spending in Japan again exceeded that in North America. In 1989, this capital spending gap widened. The capital spending forecast expects capital spending in Japan to continue to exceed capital spending in North America.

Semiconductor Equipment Demand Forecast 1990 to 1991

The equipment demand forecast by segment is shown in Table 7-4. The market reached an all-time high in 1989 with total sales of $5,887 million, which represented a growth of 20.4 percent over 1988. The market is expected to slow down, however, and 1990 sales are projected to be $5,714 million, for a negative growth of approximately 3.0 percent. We expect 1991 sales will be up at $6,832 million. The overall CAGR for the total equipment market is forecast to be 7.7 percent from 1989 to 1991.

Capital spending as a percentage of production is shown in Figure 7-5. Capital spending as a percentage of production exceeded 30 percent in Japan in 1984 and in 1985, compared with 23 and 21 percent for capital spending in North America. However, in 1986 and 1987, the ratio of capital spending to production in Japan fell below the ratio of capital spending to production in North America. In 1988, the ratio of capital spending to production was greater in Japan than in North America; this relationship continued in 1989. The forecast for this ratio is for it to continue to be higher in Japan than in North America.

The largest equipment segment is that of lithography, followed by deposition and etch and clean. Recently, deposition has been the most rapidly growing segment; however, lithography equipment growth is expected to lead the way through 1991. Deposition is forecast to have a 6.7 percent CAGR from 1989 through 1991. Lithography is expected to have only a 10.2 percent CAGR during the same time frame.

The regional capital spending forecast is shown in Table 7-5. Capital spending is forecast to decline by 2 percent in 1990 and grow at a rate of 26 percent in 1991. Most of the predicted decline may be attributed to Japanese producers as their capacity utilization falls off somewhat due to the forecast decline in semiconductor production (see Chapter 6). Dataquest forecasts a healthy increase in demand for semiconductor equipment beyond 1990 as device production is forecast to expand vigorously in all regions.

The regional demand for equipment during the forecast period follows the semiconductor production and capital spending pattern forecast in Chapter 6 (see Table 7-4). We expect the Asia/ROW and European regions to show the most capital spending growth with 1989 to 1991 CAGRs of 12.2 percent and 18.5 percent, respectively. Capital spending for US and Japanese companies is much greater but is forecast to grow more slowly due to the forecast production slowdowns in these two regions. The forecast for capital spending by region of production, regardless of company origin, is shown in Figure 7-6.

In terms of dollars, the spending levels within Japan by Japanese and American producers will exceed spending levels in North America by substantial margins. In 1990, our forecast calls for capital spending in Japan to be 135 percent of capital spending in North America. By 1991, spending in Japan will be 149 percent of capital spending in Europe.

Strategic Issues Regarding the Equipment Demand Forecast

Impact of Regional Economy on the Forecast

The regional economic forecasts were provided in Chapter 3 and related to semiconductor production in Chapter 6. The fundamental economic impact on equipment demand is that which modulates semiconductor production and therefore demand for equipment that upgrades competitiveness or expands capacity. The relaxation of economic growth forecast worldwide, particularly in the United States, probably will moderate demand and production of semiconductors in 1990, especially in Japan, causing a predicted negative demand growth for equipment that year.

Table 7-4

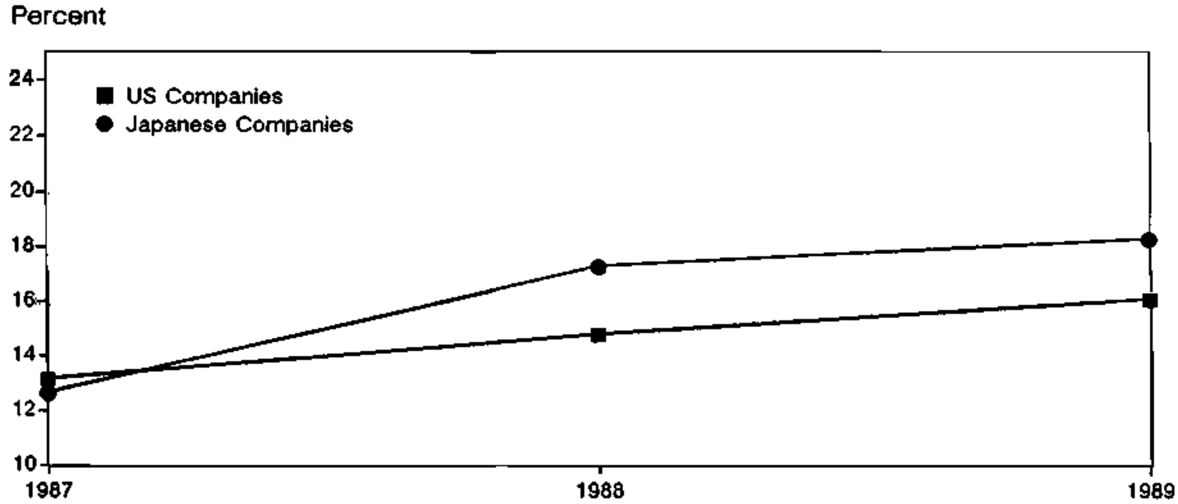
Worldwide Wafer Fab Equipment Forecast (Millions of Dollars)

	1989	1990	1991	CAGR 1989-1991
Lithography				
Contact/proximity	20	20	22	4.9%
Projection aligners	94	90	122	13.9%
Steppers	1,191	1,225	1,450	10.3%
Direct-write e-beam	70	72	80	6.9%
Maskmaking e-beam/laser	73	74	86	8.5%
X-ray	5	4	6	9.5%
Total Lithography	1,453	1,485	1,766	10.2%
Automatic Photoresist Processing Equipment	325	330	390	9.5%
Etch and Clean				
Wet process	306	293	350	6.9%
Dry strip	116	110	130	5.9%
Dry etch	636	620	732	7.3%
Ion milling	9	10	12	15.5%
Total Etch and Clean	1,066	1,033	1,224	7.2%
Deposition				
Chemical vapor deposition	580	560	675	7.2%
Physical vapor deposition	377	360	432	7.0%
Silicon epitaxy	72	46	61	(8.0%)
Metalorganic CVD	44	45	50	6.6%
Molecular beam epitaxy	73	75	85	7.9%
Total Deposition	1,145	1,086	1,303	6.7%
Diffusion	327	300	375	7.1%
Rapid Thermal Processing	28	26	34	10.2%
Ion Implantation	468	417	509	4.3%
CD/Wafer Inspection	187	195	238	12.8%
Other Process Control	485	470	553	6.8%
Factory Automation	195	170	204	2.3%
Other Wafer Fab Equipment	206	202	236	7.0%
Total Wafer Fab Equipment	5,887	5,714	6,832	7.7%

Note: Columns may not add to totals shown because of rounding
Source: Dataquest (August 1990)

Figure 7-5

Semiconductor Capital Spending
as a Percent of Semiconductor Sales



Source: Dataquest (August 1990)

Table 7-5

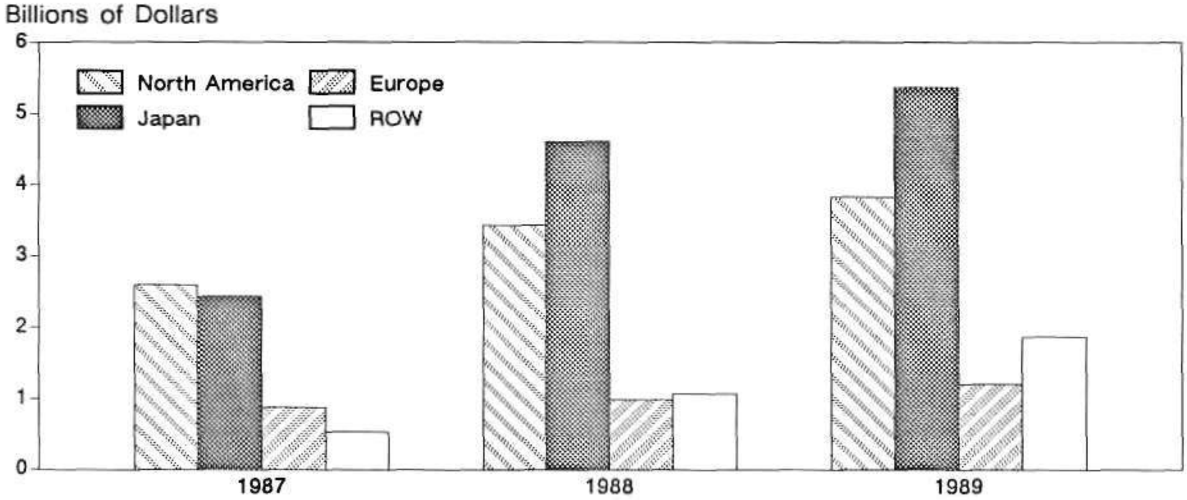
Regional Capital Spending
1989-1991
(Includes Captive Production Capital Spending)

	1989	1990	1991	Share 1989	Share 1991	CAGR 1988-1990
Worldwide Capital Spending						
US	3,822	3,759	4,465	31.2%	29.5%	8.1%
Japanese	5,368	5,089	6,635	43.8	43.9	11.1%
European	1,201	1,273	1,686	9.8	11.2	18.5%
ROW	1,854	1,877	2,333	15.2	15.4	12.2%
Total Worldwide Spending	12,245	11,998	15,119	100.0%	100.0%	11.1%
Annual Growth Rate	21.4%	(2.0%)	26.0%			

Source: Dataquest (August 1990)

Figure 7-6

Worldwide Capital Spending by Region
Regardless of Regional Company Base
1987-1989



Source: Dataquest (August 1990)

What Are the Demand Drivers for Semiconductor Production Equipment?

Analysis of new fab capacity from Dataquest's fab database reveals that almost 90 percent of the new fab capacity in 1992 will be submicron.

The majority of equipment demand is forecast to be for upgrading manufacturing technology, which equates to fine-line geometries (sub-1.5-micron), particularly the 0.7- to 0.5-micron, 200mm wafer fab capability required for 1Mb DRAMs and beyond. Therefore, equipment segments that contribute to such fab capabilities will be in higher demand.

Regional Demand/Production Imbalances

The major suppliers of semiconductor production equipment are identified in Table 7-6. As discussed in the previous paragraphs, the regional base of these suppliers has shifted substantially over the period from 1980 to 1990. In 1989, the Japanese took the lead in worldwide market share for all wafer fab equipment for the first time in history, capturing 46 percent of the market compared with the United States' 40 percent. However, the situation is worse for US suppliers than it appears for two reasons. First, the Japanese are becoming increasingly dominant in their own market for equipment. Their share of the 1989 Japanese market for wafer fab equipment was 74 percent, up

Table 7-6

1989 Top 10 Wafer Fab Equipment Suppliers
(Millions of Dollars)

Rank	Company	Revenue
1	Nikon	681
2	Applied Materials	438
3	Tokyo Electron, Ltd.	293
4	Canon	252
5	General Signal	186
6	Hitachi	165
7	Varian	165
8	ASM Lithography	141
9	Anelva	140
10	Silicon Valley Group	127

Source: Dataquest (August 1990)

from 67 percent in 1982. Correspondingly, the US share of the Japanese market in 1989 was 16.2 percent, down from more than 30 percent in 1982. Joint venture companies held 7.9 percent of the market. Second, in the technically critical lithography segment of advanced stepper equipment, Japanese suppliers achieved 76.6 percent of the worldwide market while the US suppliers' share fell to 12.4 percent. This is a technology that was innovated in the United States and at one point was wholly owned by US companies. This also is a technology that is critical to submicron device geometries.

The concentration of market share among the top companies that supply the semiconductor equipment demand is shown in Table 7-7. The top 10 companies hold more than 52.0 percent of the market, and the top 20 control more than 71.0 percent. Furthermore, Table 7-8 illustrates the relative sizes of the wafer fab equipment suppliers. The top 15 companies (11.6 percent of all suppliers) are the only suppliers with revenue in excess of $100 million. The 82.2 percent of the companies, which total 106, have revenue below $50 million. In fact, less than 25.0 percent of the companies account for more than 80.0 percent of wafer fab equipment sales.

Many of these small companies are in niche markets and have opportunities for success and growth. However, the large companies have a firm lock on the bulk of the market. Three of the top five companies are Japanese.

Table 7-7

Worldwide Revenue of Ranked Companies in Key Equipment Areas (Millions of Dollars)

Companies by Rank	1989 Revenue ($M)	Percentage of Subtotal Fab Equipment
1-10	$2,587	52.1%
11-20	974	19.6
21-30	505	10.2
31-129	904	18.2
Subtotal Wafer Fab Equipment	$4,970	100.0%
Total Market	$5,887	

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1990)

Table 7-8

1988 Revenue Breakdown of Wafer Fab Equipment Companies (Millions of Dollars)

	Number of Companies	Percent of Companies	Cumulative Percent
0 to $5	39	30.2%	30.2%
$5 to $10	22	17.1	47.3%
$10 to $25	34	26.4	73.6%
$25 to $50	11	8.5	82.2%
$50 to $100	8	6.2	88.4%
$100 to $200	11	8.5	96.9%
$200+	4	3.1	100.0%
	129	100.0%	

Note: Columns may not add to totals shown because of rounding
Source: Dataquest (August 1990)

Access to Capital

Concern exists that the ability for small companies to access sufficient investment capital through the US financial community is so limited that the most successful and strategically positioned companies become targets for acquisition by larger Japanese or European companies. Such acquisitions set up situations where innovative and creative entrepreneurs build a company around key new technologies only to stall out through failure of the financial community to respond appropriately to the strategic significance of the venture.

This situation allows foreign investors with more strategic vision and more patient capital to "cherry-pick" keystone technologies for themselves with little of the entrepreneurial risk. By this means, the independent, free-enterprise system of the United States could become a low-cost "breeding ground" for critical manufacturing technologies with which the Japanese maintain their superior competitiveness.

Continuation of these conditions all but guarantees further erosion of key new semiconductor manufacturing technologies to Japanese equipment suppliers, adding to the staggering regional imbalances that already exist. In the long term, such conditions gradually will eliminate the independent semiconductor producer within the United States. Except for a few specialty areas such as 32-bit microprocessors and the recent SEMATECH effort where the United States has recognized the problem and protected its long-term interests, this loss of domestic semiconductor suppliers would, over time, eliminate the United States as the dominant force in computers, communications, and industrial electronic equipment.

CHAPTER 8

Executive Summary and Conclusions

This chapter presents a summary of the key points from the preceding chapters.

Overview

- In 1989, worldwide merchant semiconductor industry revenue totaled $57.2 billion. This represents a modest 12 percent growth over 1988 and a more than doubling of annual revenue in just four years since the 1985 recession.
- The semiconductor industry is part of the electronics industry, the infrastructure, which is made up of a complex chain of buyers and sellers working together to satisfy worldwide demand for electronic products. This chain consists of several tiers beginning with the demand for electronic equipment, continuing to semiconductor devices, and ending with the demand for semiconductor equipment and materials. Demand for various products flows through the buyer/seller chain from one level to the next, producing a cascading "waterfall of demand."
- Success of the $653.1 billion electronic equipment industry and the $57.2 billion semiconductor industry is dependent on the $18.0 billion semiconductor equipment industry.

Key Economic Points

- Electronic equipment represents nearly 7 percent of the OECD members' output of goods and services. This amounts to $653 billion out of $10 trillion, measured in US dollars.
- Of the three economic sectors—private business, government, and consumer—demand for semiconductor devices is most influenced by private business. Within private business, semiconductor demand is influenced most by capital spending.
- Since 1987, the global economy has been expanding vigorously due primarily to capital spending by businesses.
- Worldwide economic growth is forecast to slow over the next two years.

Semiconductor Demand Summary

- The following three electronic equipment segments are the major contributors to semiconductor growth:
  - Data processing
  - Consumer equipment
  - Communications
- Major growth products have been personal computers, workstations, storage peripherals terminals, personal printers, VCRs, and compact disc players.
- As Japanese and Asian economies surge, they are consuming larger percentages of worldwide electronic equipment; in 1989, they equaled the European economy in size.
- Electronic equipment growth products have the following common attributes:
  - High semiconductor content
  - High unit volume
  - Large market (all of these products are utilized by individuals and thus are ensured of a large total available market)
- Semiconductor demand is dependent on the following:
  - Equipment production growth worldwide
  - Semiconductor pervasiveness has grown from 7.3 percent in 1986 to 9.3 percent in 1989. Semiconductor pervasiveness is measured as the dollar content of semiconductors as a percentage of the dollar value of the finished equipment.

- North America still is the dominant producer of data processing, communications, and industrial electronic products, but a clear trend has emerged that indicates significant erosion in market share for North American suppliers.

- After a decline in the first quarter of the year, worldwide semiconductor demand is forecast to grow through the second half of 1990 as the demand for electronic equipment increases. Worldwide merchant semiconductor demand growth for 1990 is forecast to be a negative 0.7 percent before growing 17.0 percent in 1991. The merchant market is expected to reach $58.2 billion in 1989 and decline to $57.9 billion in 1990.

Semiconductor Production Summary

- With more than 200 companies throughout the world producing semiconductor devices, the Japanese have four out of the top five companies. The top five semiconductor producers are NEC, Toshiba, Hitachi, Motorola, and Fujitsu, in that order.

- Japanese and Asia/Pacific countries have become the dominant forces in the semiconductor industry.

- The demand for semiconductors has shifted dramatically over the last four years as indicated in the following sentences:

  - In 1984, the Japanese and Asia/ROW regions represented $11 billion or only 38 percent of the $29 billion total, while North America's share was $13 billion, or 45 percent.

  - As the North American share of electronic production declined, the semiconductor demand market share fell from 45.0 percent in 1984 to 34.9 percent in 1989.

- Semiconductor product opportunities for the next few years are in the following areas:

  - ASICs
  - Specialty memories—FERRAMs
  - Intelligent power systems
  - Microcomponents

- MOS memory revenue has become a significant factor in measuring the health of the industry. The price of DRAMs can inflate or deflate the overall industry sales volume, causing a distorted view of growth or decline.

- DRAM business is forecast to decline by 32 percent in 1990 and increase by 28 percent in 1991. This DRAM decline will contribute to a slowdown in the overall semiconductor industry in 1990.

- In 1989, MOS memory revenue composed 29 percent of the total merchant semiconductor revenue of $57.2 billion.

- Japanese and Korean producers have 73 percent of the merchant MOS memory market.

- MOS memory and microcomponents were the growth areas in 1989.

- The standalone semiconductor industry as it exists in the United States is threatened by the integrated industry as it exists in Japan. The critical question for US merchant suppliers is: Can US suppliers remain independent and survive?

- Another key question regarding the future of the US semiconductor industry is: Can US suppliers obtain the necessary funds to keep up with Japanese investments?

Semiconductor Equipment and Materials Summary

- We expect semiconductor equipment demand in 1989 and 1990 to be driven by the need for new technology as fab lines come on-line with line geometries of less than 1.5 micron.

- Of all semiconductor materials, only two, silicon and photoresist, have strategic significance.

- Demand for semiconductor equipment is driven by the following:

  - Additional capacity—Producers need to expand capacity.

  - New technology—Producers need to increase competitiveness through new manufacturing technology.

- Manufacturing technology focus is on fab lines that have less than 1.5-micron geometries.
- By 1992, almost 60 percent of the square inches of silicon consumed will have line geometries of less than 1.5 micron.
- The key technology demand drivers for manufacturing equipment is in the front-end (wafer fab) process-related equipment that will do the following:
  - Produce fine-line geometries and provide more functions per die
  - Process larger wafers and yield more die per wafer
  - Minimize contamination and improve yields (track systems)
- X-ray lithography may well be the next critical technology in the pursuit of submicron geometries. Japan recognizes this and is making significant investments.
- Capital spending within semiconductor producers is forecast to grow at an annual rate of 11.6 percent in 1989 and decline slightly in 1990, followed by a healthy demand beyond 1990 as device production expands in all regions. The bulk of the decline in 1989 is forecast to be from Japanese producers as their capacity utilization falls off.
- The top ten companies (10 percent of all suppliers) are the only suppliers with revenue in excess of $100 million. Sixty companies have annual revenue below $50 million.
- Adequate capital is not available within the United States to fund new semiconductor equipment technologies, which leaves an opening for foreign investors to cherry-pick the best technologies. This will cause further elimination of US-based independent suppliers and further weakening of the US semiconductor industry.

United States—Summary Statements

- The US electronics and semiconductor industries are facing critical problems, described as follows:
  - First, the US market for semiconductors is shrinking as a percentage of the worldwide market because of the erosion of market share by US electronics companies.
  - Second, Japanese and Asian semiconductor companies continue to gain share within the United States, while US semiconductor producers are not gaining share in Japan or other Asian countries.
- The three primary causes for the dramatic shift in the balance of economic power between the United States and Japan are shown as follows:
  - Many North American equipment producers moved offshore.
  - A shakeout of US suppliers occurred.
  - The change in the exchange rate caused by the devaluation of the dollar beginning in 1986 caused an inflated view of the Japanese market share.
- The United States now is at risk of becoming a minor player in worldwide electronics market during the last decade of the century.
- Because nearly one-half of the world GNP is contributed by the United States, the continued health of the world economy depends on the health of the United States.
- The US economy is projected to have slower growth beginning in late 1990 and lasting through 1991.

APPENDIX A

Directory of Semiconductor Suppliers

ACC Microelectronics
3333 Bowers Avenue, Suite 215
Santa Clara, CA 95054
408/980-0622

Actel Corporation
955 E. Arquez Avenue
Sunnyvale, CA 94086
408/839-1010

Acumos, Inc.
1531 Industrial Road
San Carlos, CA 94070
415/591-1488

Adaptec, Inc.
691 S. Milpitas Boulevard
Milpitas, CA 95035
408/945-8600

Advanced Hardware Architectures
P.O. Box 9669
Moscow, ID 84843
208/883-8000

Advanced Linear Devices, Inc.
1180 F. Mariloma Way
Sunnyvale, CA 94086
408/720-8737

Advanced Micro Devices, Inc.
901 Thompson Place
P.O. Box 3453
Sunnyvale, CA 94088
408/732-2400

Advanced Microelectronic Products, Inc.
North American Headquarters
1887 O'Toole Avenue, Suite C-111
San Jose, CA 95131
408/727-8880

Advanced Power Technology, Inc.
405 S.W. Columbia Street
Bend, OR 97702
503/382-8082

Altera Corporation
2610 Orchard Parkway
San Jose, CA 95134-2020
408/984-2800

ANADIGICS, Inc.
35 Technology Drive
Box 4915
Warren, NJ 07060
201/668-5000

Applied Micro Circuits Corporation
6195 Lusk Boulevard
San Diego, CA 92121
619/450-9333

Analog Devices, Incorporated
One Technology Way
P.O. Box 9106
Norwood, MA 02062-9106
617/461-3612

Asahi Kasei Microsystems Co., Ltd.
Imperial Tower 1-1
Uchisaiwai-cho 1-chome
Chiyoda-ku, Tokyo, JP

ASEA AB Head Office
S-721 83 Vasteras
Sweden
46 21 10 00 00

ASEA Brown Boveri
Box 520, S-175 26
Jarfalla, Sweden
010 46 758 24500

Aspen Semiconductors
58 Daggett Drive
San Jose, CA 95134
408/432-7050

AT&T Microelectronics
555 Union Boulevard
Allentown, PA 18103-9989
1-800-372-2447

Atmel Corporation
2125 O'Nel Drive
San Jose, CA 95131
408/441-0311

Austek Microsystems Pty. Ltd.
Technology Park, Adelaide
South Australia 5095, Australia
8/260-0155

Austria MikroSysteme International
Schloss Permstatten
8141 Unterpremastatten
Austria
010 43 31363666271

Bipolar Integrated Technology
1050 Northwest Compton Drive
Beaverton, OR 97006
503/629-5490

BKC International Electronics
6 Lake Street
P.O. Box 1436
Lawrence, MA 01841
508/681-0392

Brooktree Corporation
9950 Barnes Canyon Road
San Diego, CA 92121
619/452-7580

Burr-Brown Corporation
6730 South Tucson Boulevard
Tucson, AZ 85706
602/746-1111

California Micro Devices Corporation
215 Topaz Street
Milpitas, CA 95035-5430
408/263-3214

Calmos Systems, Inc.
20 Edgewater Street
Kanata, Ontario, Canada, K2L 1V8

Calogic Corporation
237 Whitney Place
Fremont, CA 94539
415/656-2900

Catalyst Semiconductor, Inc.
2231 Calle De Luna
Santa Clara, CA 95054
408/748-7700

Celeritek, Inc.
617 River Oaks Parkway
San Jose, CA 95134
408/433-0335

Chartered Semiconductor Pte. Ltd.
3-lim Teck Kim Road
STC Building 10-02
Singapore 0208

Cherry Semiconductor Corporation
2000 South County Trail
East Greenwich, RI 02818
401/885-3600

Chips & Technologies, Inc.
3050 Zanker Road
San Jose, CA 95134
408/434-0600

Cirrus Logic, Inc.
1463 Centre Pointe Dr.
Milpitas, CA 95035
408/945-8300

Comlinear Corporation
4800 Wheaton Drive
Fort Collins, CO 80525
303/226-0500

Cree Research Inc.
2810 Meridian Parkway
Durham, NC 27713
919/361-5709

Crystal Semiconductor Corporation
4210 South Industrial Road
P.O. Box 17847
Austin, TX 78760
512/445-7222

Custom Arrays Corporation
525 Del Rey Avenue
Sunnyvale, CA 94086
408/749-1166

Cypress Semiconductor Corporation
3901 North First Street
San Jose, Ca 95134-1599
408/943-2600

Daewoo Telecommunications Co., Ltd.
541 Namdaemun-ro 5-ga
Chung-gu, Seoul, Korea
02-771-35

Dallas Semiconductor Corporation
4350 Beltwood Parkway South
Dallas, TX 75224
214/450-0400

The DSP Group, Inc.
1900 Powell Street, Suite 120
Emeryville, CA 94608
415/655-7311

Edsun Laboratories
564 Main Street
Waltham, MA 02154
617/647-9300

Elantec, Inc.
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