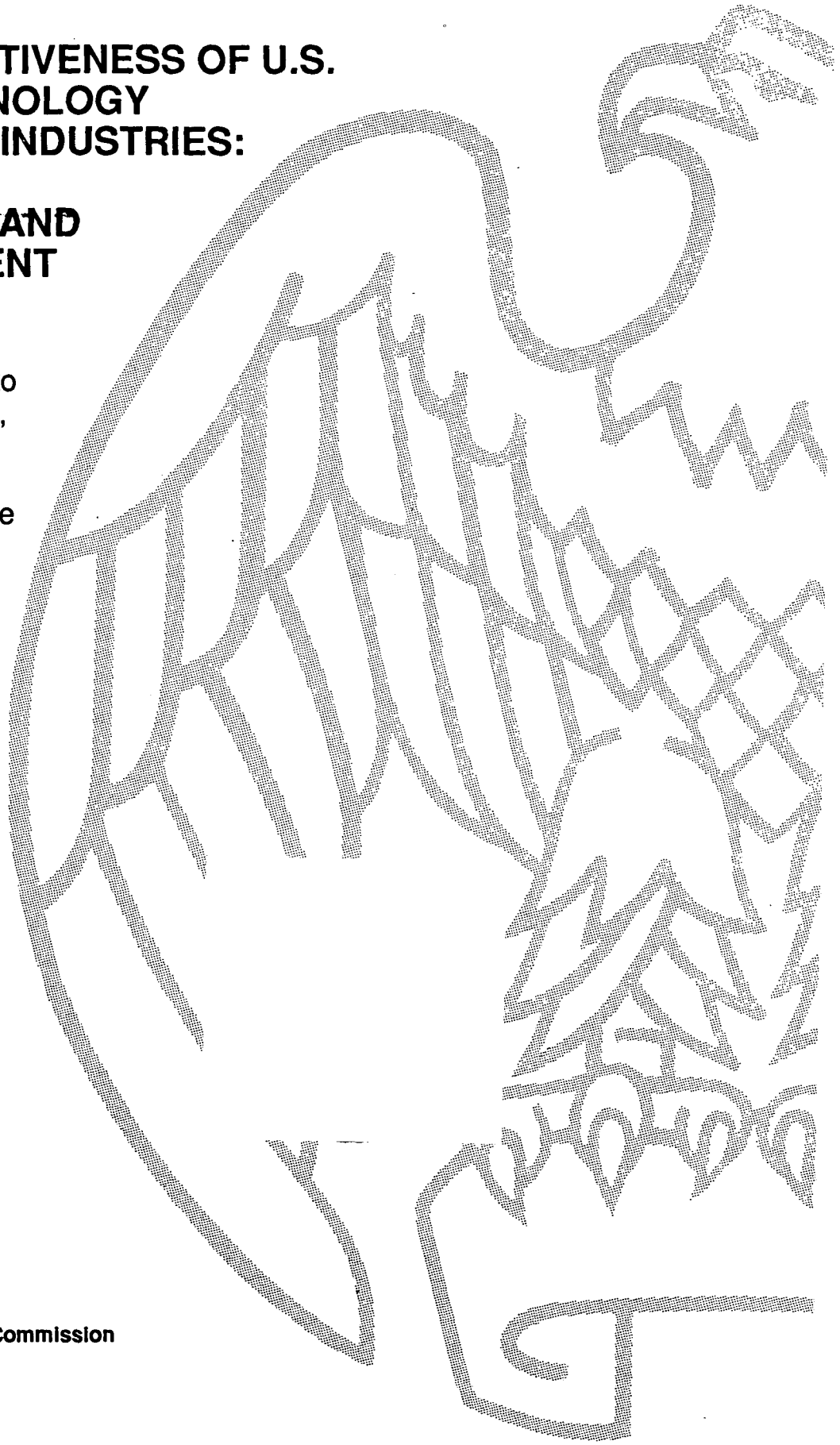
_OBAL COMPETITIVENESS OF U.S. DVANCED-TECHNOLOGY ANUFACTURING INDUSTRIES: EMICONDUCTOR ANUFACTURING AND ESTING EQUIPMENT

Summary of the Report to e Committee on Finance, iited States Senate, on vestigation No. 332-303 ıder Section 332(g) of the riff Act of 1930



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INTRODUCTION

This summary reviews the principal factors affecting the competitiveness of the U.S. semiconductor manufacturing and testing equipment and materials (SEM) industry presented in the U.S. International Trade Commission's report, *Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment* (henceforth called the report).[1] The Commission's report, as requested by the Senate Committee on Finance, identifies the principal competitive determinants in the SEM industry and provides an analysis of the factors that shaped the industry during 1980-90, such as product performance, market location, relations with customers, and various government policies. The report compares the performance of the U.S. industry with that of Japan, and to a lesser extent, with that of Western Europe. Any conclusions or inferences contained in this summary are based upon the information and analysis found in that report.

The data provided in the report were collected from primary sources through interviews with government and industry officials, both domestic and foreign, and from testimony presented by interested parties at the Commission's public hearing. In addition, officials of U.S. and Japaneses SEM firms provided information on how they ranked the relative importance of the external and internal factors affecting the competitiveness of the SEM industry. The results of the survey are presented later in the summary.

Products

The SEM industry produces a variety of machines and materials that are used to manufacture integrated circuits and other semiconductor products. These include (1) silicon wafer-manufacturing equipment; (2) wafer-processing equipment; (3) assembly equipment; (4) testing equipment; and (5) processing and packaging materials. Wafer-manufacturing equipment consists of furnaces, vacuum chambers, saws, and polishing apparatus used to produce silicon wafers. Wafer-processing equipment covers a broad range of apparatus, including photolithographic equipment that is used to create images on the wafers, diffusion and oxidation equipment to change the electrical characterics of the wafers, ion implantation equipment to introduce impurities into the wafers, and etching and cleaning equipment to remove materials from the wafers and prepare them for the next processing step. Assembly equipment includes die bonders, wire bonders, encapsulation equipment, and other apparatus used to package semiconductor devices. Testing and measuring equipment include the instruments and machines that are used to discover defects during production and ensure that design dimensions are achieved during processing steps. Silicon wafers, leadframes, ceramic packages, and encapsulation compounds are the principal types of processing and packaging materials.

Global Producers

In 1990, the world market for semiconductor manufacturing and testing equipment amounted to $9.3 billion and the world market for processing and packaging materials totaled $9.2 billion. U.S. firms supplied 45 percent of the semiconductor manufacturing and testing equipment market and Japanese firms supplied almost 44 percent.[2] However, Japanese firms supplied 73 percent of the processing and packaging materials market compared with only 13 percent by U.S. firms. The top three equipment producers in 1990 were Tokyo Electron Ltd. (Japan), Nikon (Japan), and Applied Materials (U.S.). Together, these three firms supplied almost 22 percent of world production of semiconductor manufacturing and testing equipment. The top three producers of processing and packaging materials were Kyocera (Japan), Shin-Etsu Handotai (Japan), and NTK (Japan). These three firms supplied more than 16 percent of processing and packaging materials.

Linkages

The U.S. SEM industry is the principal supplier to the $25-billion U.S. semiconductor industry, which in turn supplies many of the most advanced components used by the $266-billion U.S. electronics industry. The three industries support each other not only through sales and purchases but also through shared technology. Cooperation between SEM and semiconductor firms improves the products of the former and the production capabilities of the latter, while cooperation between semiconductor and electronics firms enables the latter to improve product performance by incorporating more electronic functions on increasingly complex silicon chips. The presence of competitive U.S.-based firms in each of the three industries improves the competitive performance of the others.

AN ANALYTICAL FRAMEWORK FOR COMPETITIVENESS IN THE SEM INDUSTRY

The report defines the "competitiveness" of particular SEM firms as their ability to sustain relative global market position (sales volume and market share) and profit performance in the context of rapidly changing technology and markets. Sales volume, particularly when measured in market share, directly

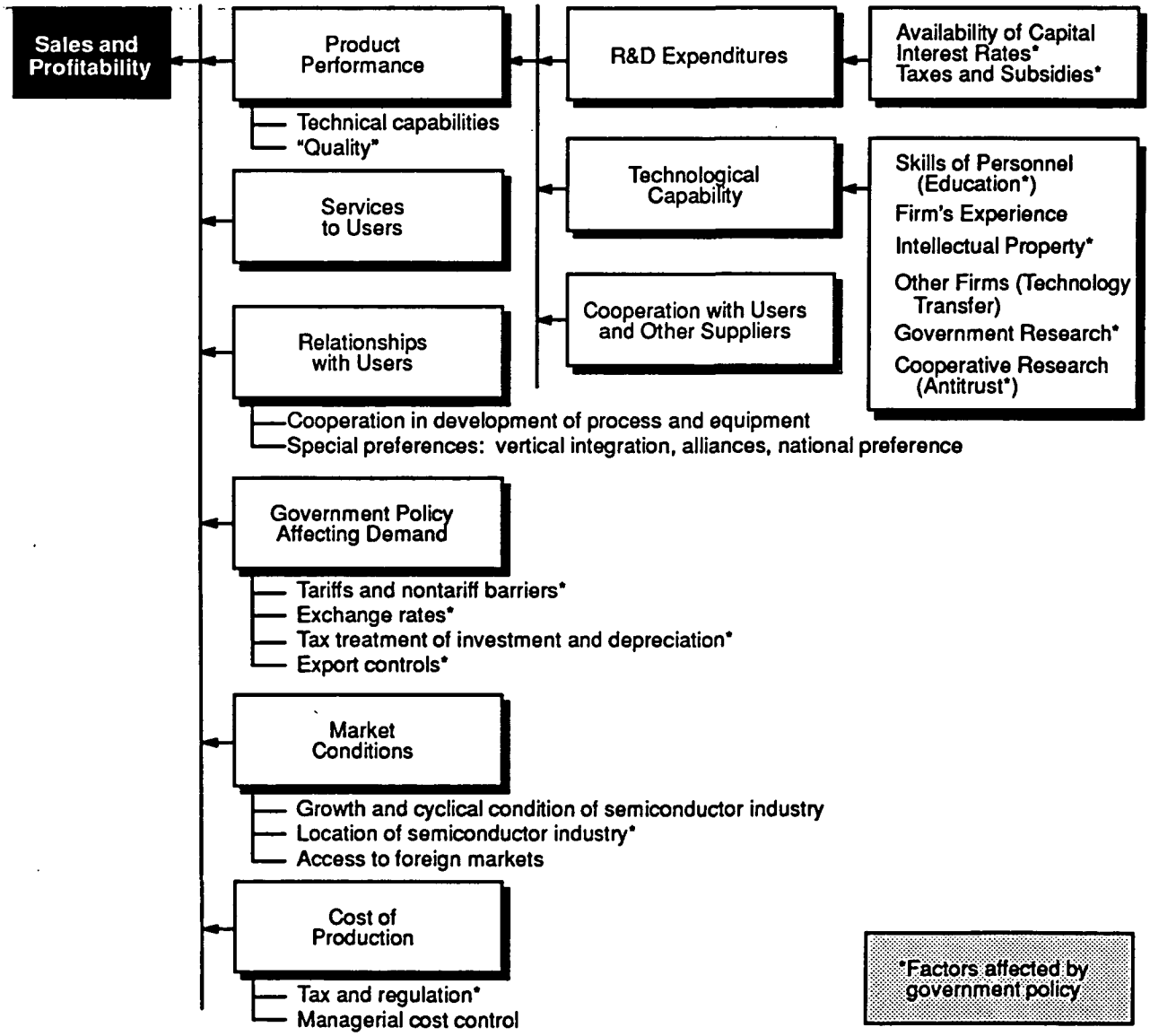
[1] U.S. International Trade Commission inv. No. 332-303.

[2] The U.S. SEM industry as treated in this study encompasses all firms headquartered in the United States. The sales of foreign affiliates of U.S. firms are counted as U.S. sales. The same treatment is accorded the SEM industries of foreign countries because (1) major decisions, (2) most R&D, and (3) much of the value added in a SEM product (R&D, know-how, and critical components) are from/made in the headquarters country. Value data in this study are expressed in nominal terms.

shows the firm's marketing success compared with its competitors. Profitability indicates the firm's business success and determines whether the firm remains in operation. These measures of competitiveness apply not only to individual SEM firms, but also to the industry as a whole.

Figure 1 charts potential causal relationships among the factors that industry participants and others have identified as important measures and determinants of competitiveness. Column 1 indicates that sales and profitability are the principal measures of the competitiveness of a SEM supplier and column 2 identifies product performance and other factors as the direct determinants of sales and profitability. Product performance in turn is determined by R&D expenditures and other factors listed to its right. Items listed below each box in column 2 describe important aspects of each competitive factor.

Figure 1
Analytical framework for competitiveness in the SEM industry



The direct determinants of competitiveness are essentially the factors governing demand and supply for a SEM firm's products. The first four factors in figure 1 are those that users emphasize most in choosing among alternative SEM suppliers: the technical performance of the equipment or material, the services that suppliers provide along with their product, long-term relationships between particular suppliers and users, and government policies that affect demand for equipment and materials. The fifth factor (market conditions) represents the overall size of the SEM firm's market, and the sixth factor (cost of production) represents part of the supply side of competitiveness.[3] While several of these factors depend primarily on the actions of the SEM suppliers themselves, others reflect the structure of markets, the general economic environment, government policy, and other external elements.

Product Performance

Product performance includes, first, the technical capabilities of the product. For example, these include the minimum feature size (or linewidth) that photolithographic equipment and materials are capable of generating, or the wafer size (6 inch, 8 inch, etc.) that any equipment is able to handle. Second, product performance includes several attributes related to "quality." For equipment, these include reliability (often measured in terms of uptime) and throughput (number of wafers processed per hour). For materials, the most important issues of quality are purity, for chemicals, and absence of defects, for other materials.

The development of equipment or materials that perform competitively depends upon the firm's spending on R&D, its technological capability[4] (i.e., its ability to develop new technology), and its cooperation with users. In turn, R&D expenditures depend, in part, upon the availability of capital, which may come either from the firm's retained earnings, a parent corporation, or capital markets. They also depend upon interest rates as well as tax treatment of R&D. The firm's technological capability is the result of the skills of its personnel, the experience of the firm with the relevant technologies, and the firm's acquisition of technology from outside sources (such as other firms, government laboratories, and research consortia). The availability of technology from outside sources depends on government policy related to intellectual property rights, government research, and antitrust regulations.

Cooperation with users plays two roles in developing the performance of products. First, suppliers learn of customers' desires for the features of future products. Second, cooperation with users provides an opportunity to improve products based on experience under operating conditions.

Other Factors Affecting Choices of SEM Users

The value of a SEM product to users depends not only on the characteristics of the product itself, but also on the package of services offered by the supplier. The quality of product demonstration, training of operators or handlers, and equipment setup and maintenance all contribute to long-term sales performance.

An important extension of a SEM supplier's service to users is cooperation with users in developing both the users' production process and (as noted above) the supplier's product. Increasingly, SEM product users seek help from their suppliers in improving process control. Other sorts of relationships between suppliers and users, especially geographic nearness or common nationality, may lead to special preferences for a particular supplier's product.

The fourth direct determinant of competitiveness in figure 1 covers government policies that affect SEM users' purchases. Tariffs and exchange rates affect the prices of imported products only, thereby influencing customers' choices between imported and domestic products. Tax treatment of capital investment and equipment depreciation affects the net price to the equipment customer of both foreign and domestic products, thereby influencing total purchases. Because equipment users tend to buy more domestic than foreign equipment, this tax treatment affects the domestic SEM industry more than the foreign SEM industry. Other policies that may affect demand include nontariff trade barriers and export controls.

Market Conditions and the Cost of Production

The demand that a SEM firm faces for its equipment also depends upon market conditions facing its customers, who are firms in the semiconductor industry. That industry is a fast-growing but highly cyclical one, and its demand for equipment is even more volatile than its production. The location of ownership and production in the consuming industry matters as well, inasmuch as SEM suppliers have historically held a greater market share in their local markets. A SEM firm's ability to establish a presence in foreign markets is another factor affecting its competitiveness.

Finally, competitiveness depends upon the cost of production. Lower input costs lead directly to higher profits and indirectly to greater sales, as they enable firms to price their products more competitively. Costs depend in part upon general economic conditions such as wage rates, taxes and regulations, and the effectiveness of management in controlling costs. What matters with respect to all these factors, of course, is not absolute performance but relative

[3] Other aspects of the supply side are included among factors determining product performance.

[4] The "technological capability" of a firm should not be confused with "technical capabilities", which are characteristics of product performance.

advantage, i.e., how a firm compares to its domestic and foreign competitors.

Government Policy and Competitiveness

Government policy may affect several of the factors related to competitiveness, as indicated by asterisks in figure 1. Trade policy, tax policy, exchange rates, and export controls affect the demand for the products of SEM firms. The tax treatment of R&D affects incentives to develop new technology. The firm's technological capability depends in part on intellectual property rights, research in government laboratories, government support of private research, and antitrust law related to cooperative research. Furthermore, trade agreements and the enforcement of laws against unfair trade practices may affect the location of the SEM industry's customers.

THE COMPETITIVE PERFORMANCE OF U.S. SEM SUPPLIERS

During the 1980s, the U.S. semiconductor equipment and materials (SEM) industry lost a substantial share of the world market for its products to Japanese suppliers. In 1980, the United States led every segment of semiconductor manufacturing and testing equipment except assembly equipment, while Japan shared the technological and market lead with the United States in assembly equipment and certain types of materials. By 1990, Japanese suppliers had a significant position in all major segments and nearly all product categories in the SEM industry. The United States led Japan slightly in sales of equipment, but trailed Japan substantially in sales of materials. Throughout this period Europe remained a relatively minor party, with a global market share fluctuating near 10 percent.

The remainder of this section considers, first, the performance of semiconductor equipment suppliers and semiconductor materials suppliers, as a group, in sales and profitability and, second, the performance of U.S. suppliers in particular industry segments.

Sales and Profitability of the Industry as a Whole

Sales of Equipment Suppliers

The tabulation below compares the sales of U.S.-owned semiconductor equipment firms with sales by foreign-owned firms during 1985-90. In the world market as a whole, U.S. equipment sales were slightly greater than Japanese sales in 1990. The trend over the period 1985-90, however, is toward strongly increasing sales for Japanese and third-country suppliers while sales of U.S. suppliers failed to grow at all in real terms. The world market grew by 60 percent in nominal terms during the period, but U.S. sales grew by only 17 percent. Because cumulative inflation amounted to approximately 18 percent over the period (using the U.S. GNP deflator as a measure), the real (i.e., inflation-adjusted) value of U.S. sales actually declined about 1 percent.[5]

The U.S. SEM industry's decline in world market share over 1985-90 was due largely to the change in the relative sizes of the regional markets, but it was also accounted for partly by a decline in U.S. market share within each of the regional markets, as figure 2 indicates. The U.S. industry has its greatest market share in its domestic market (an estimated 75 percent in 1990), which has grown more slowly than the other regional markets. The Japanese industry had a 76-percent share of its domestic market, the world's largest, in 1990. The U.S. industry had a substantial lead over both Japanese and third-country suppliers in third-country markets, with 47 percent.

Sales of Materials Suppliers

In the world market for semiconductor materials, U.S.-owned firms supplied about 13 percent of world consumption in 1990, while Japanese firms supplied 73

[5] Japanese sales grew by 137 percent in nominal, dollar-valued terms, and third-country sales grew by 216 percent. Because the dollar declined in value substantially against the yen and other foreign currencies between 1985 and 1987, the value of Japanese sales in constant (i.e., inflation-adjusted) yen increased 36 percent over the period, while third-country sales increased somewhat more.

Semiconductor equipment supplier and customer shares in major markets, 1985-90
By country of ownership

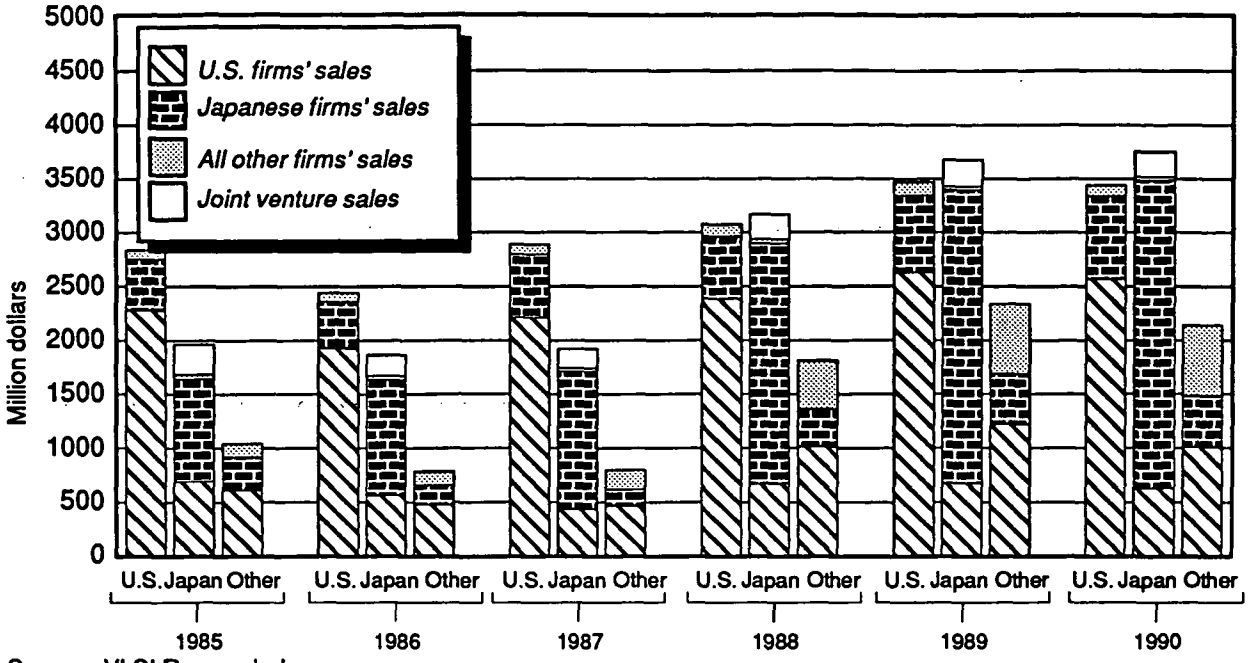
(All figures based on current dollars and current exchange rates)

	1985	*1986*	*1987*	*1988*	*1989*	*1990*[1]
World purchases ($ million)	5850	5104	5492	8063	9492	9349
U.S. sales (%)	61	58	57	51	48	45
Japanese sales (%)	30	33	34	39	41	44
Joint-venture sales[2] (%)	5	4	3	3	3	3
Third-country sales (%)	4	5	6	7	8	9

[1] 1990 figures are estimates.
[2] Joint U.S.-Japanese ventures in Japan.

Source: VLSI Research Inc.

Figure 2
Semiconductor equipment: Regional sales by producing regions, 1985-90



Source: VLSI Research, Inc.

percent and European firms supplied 14 percent. The semiconductor materials industry involves a substantial amount of production in markets other than the producers' home base. In 1990, about 23 percent of production took place in the United States, 64 percent in Japan, 7 percent in Europe, and 6 percent elsewhere. While data on the market shares of each producing region in each consuming region are unavailable, the following tabulation indicates that the United States is a substantial net importer of semiconductor materials.[6] Analysts believe that most U.S. suppliers produce almost exclusively for the domestic market, so that there is little U.S. export of semiconductor materials.

Production and consumption of semiconductor materials, 1990
(Percentage of world total)

Region	*Sales (location of ownership)*	*Sales (location of production)*	*Consumption (location of ownership)*
United States ..	13	23	38
Japan	73	64	47
Europe	14	7	10
Other countries	(1)	6	5

[1] Less than 0.5 percent

Source: See table 2.

[6] Data on consumption of semiconductor materials are based on the location of ownership of materials-using firms, not location of use.

Profitability of SEM Suppliers

There are no comprehensive data on the profitability of U.S. SEM suppliers, primarily because most suppliers (particularly small ones) are either privately held or, in some cases, are parts of large corporations that do not report financial results separately for the relevant divisions. This is particularly the case for U.S. suppliers of semiconductor materials. The tabulation at the top of the next page, however, presents information on nine large U.S. equipment-supplying firms.[7] All but one of these firms is publicly held, and all but one had sales in 1990 of $100 million or more. Together, these firms supplied approximately 45 percent of U.S. production of semiconductor equipment in 1990.[8] The period covered represents approximately one industry business cycle.

[7] The firms included are Applied Materials, Genus, KLA, Kulicke and Soffa, Lam, LTX, Novellus, SVG, and Teradyne.

[8] In earlier years, they supplied smaller fractions of U.S. output, ranging from 27 percent in 1986 to 39 percent in 1989. This increase over time reflects primarily the fact that the firms selected for inclusion here are those that are currently the largest. Due to relatively rapid changes in the relative sizes of firms in the industry, this means that the firms selected tend to be those that have recently grown the fastest.

Profitability of leading U.S. semiconductor equipment suppliers, 1986-90
(Total for nine firms, $ millions and percent of sales)

	1986	1987	1988	1989	1990
Net sales	826	911	1395	1785	1882
Cost of goods	465 (56%)	520 (57%)	759 (54%)	972 (56%)	1069 (57%)
Gross profit	361 (44%)	392 (43%)	636 (46%)	812 (44%)	813 (43%)
R&D expenditure	153 (18%)	153 (17%)	180 (13%)	245 (14%)	298 (16%)
Pretax earnings	-29 (-4%)	-44 (-5%)	91 (7%)	144 (8%)	52 (3%)
Number profitable	3	3	8	8	6

The tabulation shows that, as a group, the nine firms incurred losses during the industry recession in 1986-87, returned to positive pretax earnings during the expansion of 1988 and 1989, and experienced declining profits in 1990, when sales expansion slowed. Data for the individual firms indicate that three firms had positive pretax earnings in 1986 and 1987,[9] eight in 1988 and 1989, and six in 1990. One firm had negative earnings throughout the period, while three had positive earnings each year. According to a recent survey by the U.S. Department of Commerce,[10] smaller semiconductor equipment firms appear less likely to be profitable than larger firms, such as those in this survey. Comparable data for foreign SEM firms are not available.

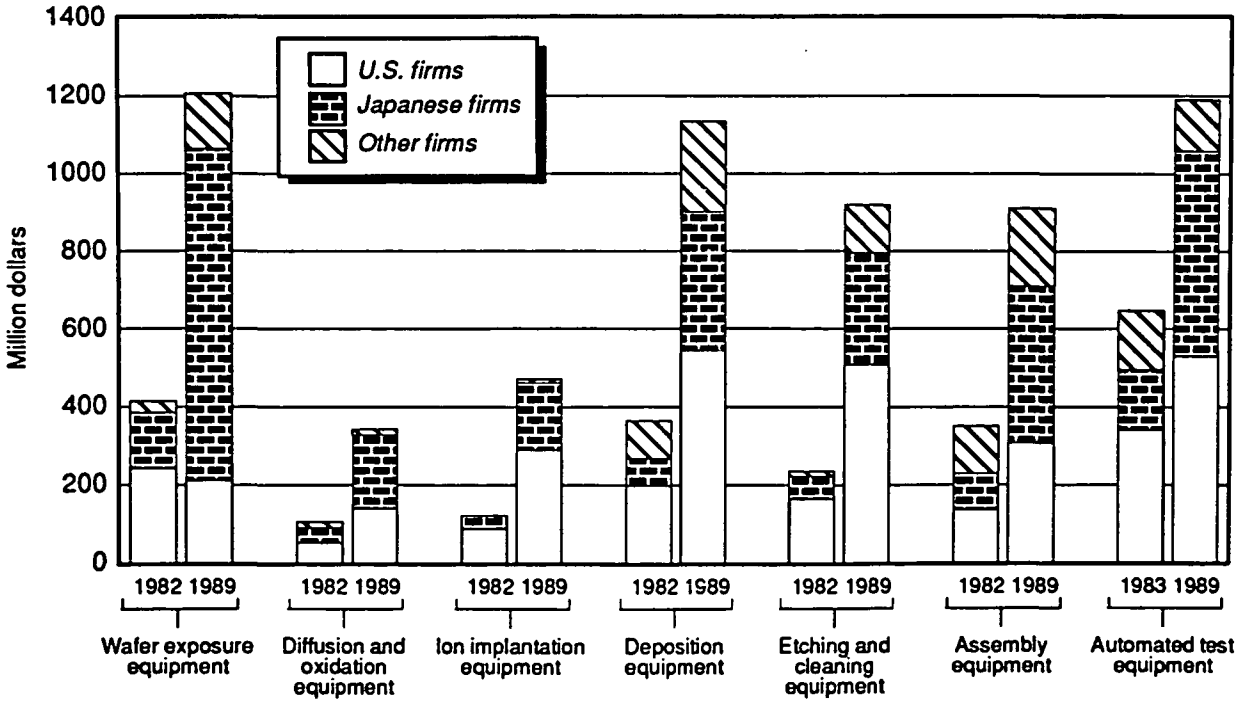
The Competitiveness of U.S. SEM Industry Segments

While the U.S. SEM industry lost market share during the 1980s in every segment of both equipment and materials, it retains world leadership in several segments of equipment, most notably ion implantation and chemical vapor deposition. As tables 1 and 2 and figure 3 show, the U.S. industry has fallen substantially behind its Japanese counterpart in photolithographic (wafer exposure) equipment, diffusion and oxidation equipment, assembly equipment, and most product categories within materials. The loss of photolithography is probably the most significant, as

[9] One firm included in the tabulation, Novellus, did not exist in 1986 and had losses associated with start-up operations in 1987.

[10] U.S. Department of Commerce, Office of Industrial Resource Administration, *National Security Assessment of the U.S. Semiconductor Wafer Processing Equipment Industry*, April 1991, pp. 33, 37.

Figure 3
Semiconductor equipment: Worldwide sales and market shares of producing regions in major product segments, 1982(3) and 1989



Source: VLSI Research, Inc., Prime Data, and other sources.

Table 1

Semiconductor equipment: World sales and U.S. and Japanese market shares, 1989

Product category	*World sales ($ millions)*	*Share of total*	*U.S. market share*	*Japanese market share*
			Percent	
SILICON WAFER MANUFACTURING EQUIPMENT	54	0.6	42	6
WAFER PROCESSING EQUIPMENT:				
Photolithographic equipment	1,647	19.5	26	63
Photoresist processing equipment	382	4.5	33	57
Wafer exposure equipment	1,207	14.3	18	71
Mask-making equipment	59	0.7	96	4
Diffusion and oxidation equipment	343	4.1	41	55
Diffusion furnaces	300	3.5	36	60
Other	43	0.5	79	17
Ion implantation equipment	471	5.6	62	37
Deposition equipment	1,135	13.4	49	33
Chemical vapor deposition	621	7.3	59	22
Physical vapor deposition	346	4.1	28	52
Epitaxy	166	2.0	45	22
Etching and cleaning equipment	920	10.9	59	38
TOTAL	4,516	53.4	43	47
ASSEMBLY EQUIPMENT:				
Dicing	81	1.0	29	64
Die bonding	93	1.1	29	40
Wire bonding	293	3.5	40	50
Molding and sealing	315	3.7	34	42
Finishing and marking	129	1.5	40	45
TOTAL	911	10.8	36	47
TEST AND MEASURING EQUIPMENT:				
Test equipment	1,235	14.6	NA	NA
Automated test equipment	1,190	14.1	45	45
Other	45	0.5	NA	NA
Wafer measuring & inspection equip	438	5.2	67	20
Burn-in equipment	65	0.8	88	12
Other[1]	1,237	14.6	NA	NA
TOTAL	2,975	35.2	NA	NA
TOTAL SEMICONDUCTOR EQUIPMENT	8,456	100	NA	NA

[1] Includes mask and reticle inspection equipment, laser repair equipment, wafer probing equipment, materials handling equipment, process monitoring equipment, and materials monitoring equipment.

Source: VLSI Research, Inc., Prime Data, and other sources.

Table 2
World sales and market shares of semiconductor materials, 1990

Product category	World sales ($ millions)	Location by ownership Japan	U.S	Europe	Location by production Japan	U.S.	Europe
		Percent					
Processing materials:							
Silicon wafers	2,010	70	0	30	58	29	11
Photomasks	1,100	69	29	1	63	32	1
Photomask blanks	143	99	1	0	99	1	0
Photoresists	242	46	42	12	49	43	7
Wet chemicals	427	42	46	12	48	41	11
Gases	580	40	32	28	42	38	14
Sputtering targets	200	78	3	19	40	52	8
Total processing	4,702[1]	64	17	18	56	33	8
Packaging materials:							
Ceramic packages	1,110	100	0	0	92	7	1
Cerdip	197	92	8	0	61	29	0
Leadframes	1,203	74	10	16	65	7	10
Molding compound	459	83	17	0	74	5	1
Bonding wire	372	84	13	3	75	16	7
Die attachment	86	24	40	37	34	65	1
Headers	60	44	0	24	43	10	23
Total packaging	3,487[1]	85	8	7	74	10	5
Total materials	8,189[1]	73	13	14	64	23	7

[1] Categories for which location data are unavailable sum to $305 million for processing materials, $860 million for packaging materials, and $1,165 million total. Total for processing materials includes double-counting of photomask blanks used in photomasks.

Source: Prepared by the staff of the U.S. International Trade Commission, based on data provided by SEMI/SEMATECH (as purchased from Rose Associates) and by Rose Associates.

this is the single most important technology used in semiconductor manufacturing, and this technology has the most important links to other technologies used in wafer processing. The high costs of product development for photolithographic equipment, and the entrenched positions of leading Japanese suppliers, will make it difficult for U.S. firms to regain a leading role. The loss of sales in diffusion furnaces is less important, both because ion implantation is replacing the role of this equipment and because there does not appear to be a large technological barrier preventing U.S. firms from developing product performance to equal that of Japanese competitors.

The largest and technologically most important segment within semiconductor equipment, photolithographic (wafer-exposure) equipment, is the segment in which the U.S. industry experienced the greatest decline, from a market share of 58 percent in 1982 to 18 percent in 1989. The two most important product types within this category were developed by the U.S. firms Perkin Elmer and GCA during the 1970s, and in the early 1980s, these firms led the industry in sales of their respective product types. During the early 1980s, the Japanese firms Canon and Nikon developed better performing versions of both product types and thereafter gained a large share of the world market.

The report reviews the process by which GCA lost its technological and market leadership to Nikon. The shift was due, in part, to the technical problems of GCA equipment and GCA's unresponsiveness to customer needs. It was also the result of Nikon's aggressive R&D efforts, backed by technical and financial support from the Japanese Government and Japanese customers, and by Nikon's own strong technological capability in both optical systems and precision manufacturing.

COMPETITIVE STRENGTHS AND WEAKNESSES OF THE U.S. SEM INDUSTRY

This section applies the analytical framework introduced in figure 1 to assess the current competitive strengths and weaknesses of the U.S. SEM industry. After considering the direct determinants of sales and profitability, it turns to the factors that affect product performance.

Product Performance

The relative strength of U.S. SEM suppliers in this area varies with the specific product. Although U.S. firms have maintained a substantial lead in the performance of several product lines, the Japanese industry has introduced certain lines that exhibit higher performance. Whereas U.S. firms have often excelled in developing innovative equipment designs, they have often trailed the Japanese industry in incremental improvement through precision engineering that enhances both the technical capabilities of equipment

and such facets of quality as throughput and reliability. It appears from statements of industry sources, however, that the U.S. industry is improving in the latter area, in part due to the work of SEMATECH and leading customers, such as IBM and Motorola.

Services to Users

Services to users have been an area of relative weakness for U.S. SEM suppliers. SEM suppliers and users in both the United States and Japan agree that Japanese suppliers often provide more extensive marketing services, better training of equipment operators, and more reliable equipment maintenance services than U.S. suppliers. Providing high-quality service is an important element in Japanese business practices and gives Japanese SEM suppliers an advantage in the Japanese market over U.S. firms, which have historically given less attention to service. In addition, the high cost of maintaining overseas employees and of establishing an extensive service network hinders U.S. firms (particularly small firms with limited capital) from establishing a service network that is comparable to networks established by Japanese competitors.[11]

Cooperation with Users

Cooperative relationships between SEM suppliers and users are another area of generally acknowledged competitive weakness for U.S. suppliers. Because SEM users gain detailed practical knowledge about SEM products under actual working conditions, feedback from users to suppliers can improve product performance. Similarly, SEM users can benefit from the direct involvement of suppliers in improving their process control, and they increasingly choose suppliers on the basis of their willingness to be involved in this way.[12] Industry sources in the United States and Japan agree that such partnerships have been a part of the Japanese way of doing business since the beginning of the industry and have conferred a substantial competitive advantage for Japanese suppliers. Relationships among U.S. suppliers and users, on the other hand, have been characterized as "project specific, cost-driven, and litigious,"[13] so that U.S. suppliers have developed their products in relative isolation from customer feedback and good information about customer needs for future products. U.S. industry sources indicate that U.S. suppliers and users are consciously seeking to follow the Japanese example in this regard, with leadership from SEMATECH and leading customers.

Support for Local Suppliers

Many U.S. and European SEM industry participants and other observers have claimed that Japanese industrial structure and a strong preference for domestic products on the part of Japanese customers are major competitive disadvantages for U.S. suppliers in the Japanese market. The evidence on the matter, however, is not conclusive. Empirically, as figure 2 above indicates, SEM users in the United States and third-country markets, as well as Japan, all tend to buy more from domestic suppliers than from overseas suppliers. Part of the reason for this, in addition to the advantage of locality, appears to be that suppliers have learned to respond to the particular desires of their local customer base. Another factor appears to be cultural barriers, particularly in language and business practices. Some U.S. and European SEM suppliers reported, for example, that their sales in Japan were greatly enhanced by their learning to adopt Japanese ways of interacting with customers. A third reason for the observed pattern of national preference appears to be the desire of semiconductor manufacturers to support their local supplier base. While SEM and semiconductor company officials in both the United States and Europe acknowledge that this desire is a factor in both of those markets, they assert that it is an even more important factor in Japan.

According to several U.S. and (especially) European SEM suppliers, Japanese semiconductor firms buy from foreign suppliers only if the foreign products are substantially different from or superior to Japanese products, irrespective of relative prices. Furthermore, according to these sources, Japanese equipment users systematically nurture local suppliers for every item of equipment or materials used in a standard production process, eventually leaving only smaller "niche" markets to foreign suppliers.

Japanese semiconductor firm officials, however, indicate that they are not so much interested in having Japanese suppliers as they are in having suppliers that demonstrate a strong commitment to meeting the desires of Japanese customers. Generally, according to these officals, this requires not only the establishment of a service network in Japan, but R&D facilities as well. Production in Japan, furthermore, is preferred.

Foreign (i.e., U.S. and European) suppliers and Japanese customers agree that Japanese customers have tended to switch from foreign to domestic suppliers, in product category after product category, when Japanese suppliers emerged with products that performed comparably to foreign products. Foreign suppliers attribute this in large part to a closed market; Japanese customers attribute this to the superior commitment of

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[11] According to one estimate, it costs approximately one million dollars annually to establish a minimal service operation in Japan consisting of one foreigner, one Japanese sales representative, and a bilingual secretary, with moderate entertainment and participation in two trade shows a year. (Interview in Japan with John Stern, Vice President of Asian Operations, American Electronic Association, May 14, 1991.)

[12] One U.S. semiconductor industry executive informed USITC staff that his firm chooses suppliers 40 percent on the basis of product performance and 60 percent on the basis of readiness to cooperate in this way (telephone interview, May 10, 1991).

[13] *SEMATECH 1990: A Report to Congress by the Advisory Council on Federal Participation in SEMATECH* (May 1990).

Japanese suppliers to customer satisfaction. There may not be much practical difference between these interpretations, for the cost of establishing a presence in the Japanese market sufficient to satisfy Japanese customers may be beyond the means of many U.S. and European suppliers, particularly as this cost must be paid up front, before there is any assurance of sales.

Some U.S. and European semiconductor officials suggest that their own recently developed interest in supporting their local supplier bases is a defensive response to their increasing reliance on Japanese suppliers for the most advanced SEM products. These officials state that their Japanese competitors generally have first access to advanced Japanese SEM products.[14] They expect that a stronger local SEM industry would provide them with a better pool of potential partners in developing their production process.[15] Nevertheless, according to some of these semiconductor company officials, they are currently caught in the dilemma of needing the most advanced Japanese SEM products in order to maintain their own competitive position. Thus they are not always able to support local SEM suppliers with the orders the suppliers need to remain in business and develop improved SEM products for the future.

The Effect of Government Policy on Demand

Government policy affecting demand, the fourth direct determinant of competitiveness listed in figure 1, is an area of competitive weakness for the U.S. SEM industry. Tariffs and nontariff barriers are not an important factor for the U.S. industry,[16] and exchange rates have been relatively favorable to U.S. exporters since the decline of the dollar over the period 1985-87. International differences in tax laws related to investment and, especially, depreciation, however, tend to increase the size of the Japanese equipment market relative to the U.S. market, and thus favor Japanese SEM suppliers over U.S. suppliers. Whereas U.S. law allows depreciation of semiconductor equipment over 5 years (which is often longer than the equipment is used), Japanese law allows depreciation over 3 or 4 years for equipment used 8 hours a day, or over less time for equipment used on multiple shifts. Export control regulations tended to hinder U.S. sales in the foreign markets in the past, but improved processing of export licenses reduced this problem in recent years, and the recent decontrol of many SEM products is expected to reduce it still further.

Market Conditions

The highly cyclical nature of demand for SEM products (equipment especially) has negative impacts on suppliers in all regions, but it is uncertain whether these effects are worse for U.S. suppliers or foreign suppliers. Trends in the regional location of the SEM market, however, are a major competitive weakness for the U.S. SEM industry. As figure 2 above illustrates, the U.S. market, where U.S. suppliers have their greatest advantage, is the slowest growing of the three regional markets. Moreover, there has been a dramatic shift in the market for the technologically most advanced equipment which may have important implications for the future competitiveness of the U.S. industry. High-density DRAMs (computer memory chips) use the smallest linewidths of any semiconductor device, and so they require the most advanced equipment and materials. Approximately 70 percent of DRAM production now takes place in Japan, and only about 10 percent in the United States. Japanese SEM suppliers are therefore in a relatively strong position to develop the most advanced products, providing them with a competitive advantage for products used in all types of devices.

Cost of Production

Cost of production does not appear to be a strong source of competitive strength or weakness for the U.S. SEM industry as a whole. International differences in the cost of production are cited primarily by European firms to explain their decisions to develop and produce equipment in the United States rather than Europe. The most important advantages the United States offers for European producers include lower labor costs (particularly wage taxes that go for social benefits), freedom to lay off workers without major severance payments, and the ease of leasing rather than purchasing facilities in the United States.

For some particular firms, however, managerial control over costs has been an important competitive weakness. Many SEM suppliers in both the United States and Europe are entrepeneurial ventures founded by engineers with little experience in business management. Often their technical skills have generated innovative products leading to strong sales and profitability even with inefficient business practices. As stronger, well-managed competitors have emerged for their product segments, however, the lack

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[14] One particular concern expressed by some U.S. and European semiconductor manufacturers is that any equipment or materials supplied only by Japanese firms may be withheld from foreign semiconductor producers, placing them at a competitive disadvantage relative to Japanese producers. According to a just-released report of the U.S. General Accounting Office, 22 out of 52 U.S. companies that have recently purchased state-of-the-art SEM products from Japanese suppliers "provided specific examples of instances in which Japanese suppliers had rejected their offers to buy advanced equipment, parts, or technologies or had delayed their delivery by more than 6 months" (U.S. General Accounting Office, "International Trade: U.S. Business Access to Certain Foreign State of the Art Technology," Washington, D.C., September 1991.)

[15] These same motivations might explain the actions of Japanese SEM customers as well.

[16] According to European SEM suppliers, nontariff barriers are applied in certain East Asian countries against Japanese SEM suppliers. These barriers, taking the form of administrative guidance by government officials to semiconductor firms, are designed to reduce dependence on Japan. U.S. and European firms reportedly increase their sales as a result.

of managerial control has become an increasing problem.

Determinants of Product Performance

Product performance, as shown in the analytical framework in figure 1, depends on R&D spending, the firm's technological capability, cooperation with users, and cooperation with other SEM suppliers. Cooperation with users is treated above, as it is also a direct determinant of sales and profit. The remaining factors are treated here.

R & D Expenditures

The level of R&D expenditures appears to be an area of competitive weakness for some U.S. SEM suppliers, due to their difficulty in raising capital for the purpose. The SEM industry is highly R&D-intensive compared to other industries. In the years since 1980, U.S. semiconductor equipment suppliers have spent, by one estimate, from 10 to 18 percent of sales on R&D, averaging about 16 percent since 1984. Comparable data on R&D spending in Japan and other supplying countries are not available.

In some segments of the SEM industry, the expenditures required to develop new products have increased dramatically over the past decade, and even over the past five years. According to a recent industry survey,[17] the cost of developing new equipment for optical photolithography (wafer exposure) was fully 10 times as large in 1990 as in 1985, while costs for developing other types of equipment rose five times or more. Consequently, the minimum market share required to remain competitive in the long term has also risen, and severe competition is likely to eliminate firms that are technologically or financially weak, leaving a more concentrated market.

The problem of financing needed R&D expenditures appears to be particularly acute for smaller U.S. SEM firms facing Japanese competition, as these firms are most vulnerable to fluctuations in earnings needed for internal financing of R&D, and suppliers of capital regard such firms as particularly poor risks.[18] Indeed, as the discussion of profitability on pages 5-6 suggests, even some larger U.S. SEM firms may lack the profitability needed to sustain the required levels for R&D. Japanese suppliers do not face a similar problem, both because there is less of a competitive threat from foreign suppliers, and because the great majority are involved in cooperative relationships with customers willing to supply R&D capital if needed, often by endorsing loans for the suppliers.

[17] Survey by SEMI/SEMATECH and Technecon, May 1991.

[18] According to a U.S.-based industry analyst, officials of lending institutions have confirmed to him on numerous occasions that they regard small U.S. firms facing Japanese competition as poor risks, even if those firms are currently profitable. (USITC staff interview, Sept. 2, 1991)

Technological Capability

Technological capability is an area of both competitive strengths and weaknesses for U.S. SEM suppliers. The success of a firm's R&D efforts depends not only on the amount of spending but also on the firm's ability to develop the technology to enable SEM products to perform as desired.[19] While U.S. firms have often introduced major product innovations, Japanese suppliers often developed improved versions that became competitive successes. They did so partly by applying their own capabilities in the relevant technologies to designs developed in the United States.

A major focus of interest in this regard is the transfer of technology from U.S. firms to Japanese firms. According to industry sources, U.S. firms have been willing to license their technology to Japanese firms, or enter into joint ventures with production in Japan, for two reasons: the difficulty and expense of establishing their own independent presence in the Japanese market, and their undercapitalization and need of cash in order to remain viable even in the U.S. market. Furthermore, some U.S. firms found the use of Japanese distributors to be a relatively easy way to enter the Japanese market, with the result, often, that the distributors gained the technology of the products and later emerged as competitors in the same line of business.[20] U.S. firms have sold partial or total ownership interests both because of their need for cash and because they have sometimes received substantially more than the firm was worth on the U.S. market.[21] Japanese suppliers have not sold ownership interests to foreign firms. Some Japanese firms are beginning to show interest, however, in establish-

[19] A SEM firm's technological capability appears to depend most importantly on two factors: the firm's experience in making previous generations of the product and other products that embody similar technologies, and the skills of its technical personnel. Nevertheless, a firm can also gain technology from several sources outside the firm. It can acquire it from other firms, both cooperatively through licensing, joint venture contracts, or the purchase of firms, and noncooperatively through review of other firms' patent filings and the reverse-engineering of equipment on the market. The firm may also benefit from work done in government laboratories. Another mechanism which has been prominent in both the semiconductor industry and the semiconductor equipment industry, particularly in Japan, is cooperative research with other firms at a "pre-competitive" stage of development of technology.

[20] For example, Tokyo Electron Limited (TEL), the world's largest SEM supplier, entered the industry as a distributor for U.S. SEM suppliers in Japan. It later became a partner for joint ventures as well.

[21] Such firms may be worth substantially more to Japanese owners than to U.S. owners precisely because Japanese owners can more easily gain access to the Japanese market.

ing joint production ventures with U.S. firms in the United States.[22]

Japanese firms have also acquired U.S. technology through reverse engineering[23] (a common and accepted practice in other producing regions as well) and reviews of patent filings. The Japanese patent system reportedly gives Japanese suppliers an advantage by requiring the transfer of information while offering little effective protection.[24]

Cooperation with Other SEM Suppliers

Cooperation among suppliers appears to be an area of growing competitive strength for U.S. firms. One focus of such cooperation is to develop integrated systems of equipment that simplify the semiconductor production process. U.S. firms are pioneering in the development of cluster tools, which provide an automated environment in which wafers are passed from one processing step to another without human handling and with minimal exposure to possible contamination. Another focus of cooperation is to combine the technological capabilities of different firms in order to develop products that none could develop alone. U.S. firms identify antitrust restrictions on joint production as a major impediment to pursuing this strategy more fully.[25]

Inter-Industry Linkages and the Self-Reinforcing Nature of Competitiveness

In two of the factors where U.S. SEM suppliers show competitive weakness, R&D finance and market location, competitiveness appears to be self-reinforcing over time. In R&D finance, this is because the current competitive success and profitability of firms often appears to put a limit upon their level of funding for the development of future products, particularly in the case of smaller U.S. firms. In market location, this is due to the sales and technology linkages between the SEM and semiconductor industries. The relative decline of the U.S. semiconductor industry both reduces the sales of U.S. SEM firms (which in turn reduces R&D funds) and limits the opportunity of U.S. SEM firms to develop their technology through cooperative relationships with the most advanced customers. Similarly, the relative decline of the U.S. SEM industry (particularly in key technologies such as photolithography) both reduces the access of U.S. semiconductor firms to the most advanced SEM products and also limits their opportunity to improve their production process through cooperative relationships with advanced suppliers.[26]

INDUSTRY VIEWS ON COMPETITIVENESS

During the course of its study, the USITC staff surveyed a broad range of U.S. and Japanese SEM suppliers on the factors that determine their competitiveness. Table 3 presents the average ratings given by these suppliers to various factors, with 1 indicating the greatest importance and 10 the least.

The U.S. SEM industry generally gave its highest ratings to factors involving product performance and technology, followed by factors related to financial viability and factors related to market conditions. Product performance, technology, and R&D took three of the top five positions in the ranking, indicating the fundamental importance that SEM suppliers attribute to product performance and the activities that lead to it.

Industry structure ranked second, apparently showing a belief that the small size of many U.S. SEM firms inhibits the firms from financing the R&D and other activities needed to compete. Two other factors related to the financial viability of firms, market share and profitability, ranked third (in a tie) and eighth, respectively. Two factors related to outside sources of finance, the cost and availability of capital, ranked somewhat lower, in 12th and 13th place.

Relations with the semiconductor industry ranked sixth in importance, reflecting the perceived value of technical feedback and a loyal customer base. Foreign market access ranked seventh, reflecting the industry's perception that this is a problem. Ranked slightly below access to foreign markets are three factors related to the strength of the domestic market for SEM products: the health of the U.S. electronics and semiconductor industries, and the loss of domestic DRAM production. Other factors affecting the domestic SEM market—the depreciation schedule,

[22] TEL recently established a U.S.-based joint venture with Varian to produce vertical diffusion furnaces in this country (Varian Annual Report 1989). This follows a long standing joint venture between the two firms in Japan for the production of ion implantation equipment.

[23] Reverse engineering may be more effective for learning about design concepts and system integration, the aspects of innovation in which U.S. firms have a relative advantage, than precision manufacturing, an area of Japanese expertise. If so, then Japanese suppliers have a competitive advantage due simply to the nature of the expertise of each national industry.

[24] See chapter 3 of the source report for further information.

[25] The National Cooperative Research Act of 1984 has facilitated joint R&D activities, such as those undertaken under SEMATECH, by applying a pragmatic "rule of reason" rather than an absolute "per se" standard to judgments on the anticompetitive effects of such activities and by eliminating the threat of treble-damage judgments in civil lawsuits. The SEM industry supports similar legislation governing cooperative production.

[26] Economists are giving increasing attention to self-reinforcing processes such as this both in general theoretical terms and in the economics of international trade in particular. It is generally recognized that, where different industries are mutually supporting in these ways, greater activity in each industry improves the performance of the others, and that there is a minimum level of activity needed in each of the supporting industries in order to sustain the whole system.

Table 3
SEM industry ratings of factors in its competitiveness

Factors	U.S. firms		Japanese firms	
	Rating (1-10)	Rank Order	Rating (1-10)	Rank Order
Price/performance	1.66	1	3.63	6
Industry structure	2.00	2	5.43	13
Cutting edge technology	2.66	3*	3.08	3*
Market share	2.66	3*	4.52	8
Research and development	2.66	3*	2.92	2
Relations with semiconductor industry	3.25	6	3.08	3*
Foreign market access	3.50	7	5.52	15
Profitability	3.66	8	3.79	7
Health of domestic electronics industry	4.25	9*	3.17	5
Health of domestic semiconductor industry	4.25	9*	2.54	1
Loss of domestic DRAM industry	4.25	9*	6.86	19
Cost of capital	4.50	12	5.48	14
Availability of capital	5.00	13	5.38	12
Depreciation schedule	5.25	14*	7.13	21
Unfair trade practices (including dumping)..	5.25	14*	7.26	22
Growth of domestic GNP	5.33	16*	4.70	9
Turnover of skilled labor	5.33	16*	4.88	11
Protection of intellectual property	5.50	18	6.43	18
Business cycle	5.66	19	4.71	10
R&D tax writeoff schedule	6.00	20	6.96	20
Export controls	7.00	21*	7.48	23
Lack of dependence on foreign firms	7.00	21*	5.57	16
Exchange rates	8.00	23	6.00	17

*Ties

Source: USITC survey.

growth of GNP, and the business cycle—receive a somewhat lower rating. Two factors affecting demand in foreign markets, export controls and exchange rates, rank still lower. The low rating given to export controls seems to reflect a belief that the current process of revisions in export controls greatly reduces past problems in this area, while the last-place ranking of exchange rates probably reflects the favorably low value of the U.S. dollar at the time of the survey.

Like the U.S. suppliers, Japanese suppliers ranked the three factors involving product performance, technology, and R&D within the top six places. The first and fifth rankings, however, go to factors rated much lower by U.S. firms: the health of domestic semiconductor and electronics industries. Japanese suppliers evidently have a stronger sense of linkage between their industry and downstream industries, which may indicate that the actual linkage is stronger in Japan than in the United States. Similarly, Japanese SEM firms rank relations with the semiconductor industry third rather than sixth among the factors.

Japanese suppliers rank their industry structure 13th among the factors, which compares to a second-place ranking for the factor by U.S. suppliers. This suggests that Japanese suppliers may experience less of a constraint due to their industry structure than what U.S. firms experience. Another difference suggesting the contrasting situations of the two national industries is in foreign market access, ranked 15th by the Japanese and seventh by U.S. firms.

CONCLUSION

The decline in the competitiveness of the U.S. SEM industry during the 1980s resulted primarily from both the decline in the performance of U.S. SEM products relative to Japanese products and the continuing shift of the market for SEM products from the United States to Japan and other foreign markets. The relative decline in U.S. product performance was in turn the result of (1) Japanese SEM industry efforts to improve technology invented in the United States, (2) effective technical cooperation between Japanese SEM suppliers and users, and (3) the superior access of Japanese SEM suppliers to financing for R&D.

The future competitive success or decline of the U.S. SEM industry is uncertain, but it appears to depend chiefly on (1) the success of cooperative relationships with domestic or foreign customers, (2) the development of stable sources of financing for R&D, and (3) the growth of the domestic market for SEM products and the ability of U.S. firms to establish a presence in foreign markets. While all of these factors depend in part upon actions of the firms themselves, they also depend upon government policy and the structure of domestic and foreign markets.