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Chapter Author: David B. Yoffie

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7 Foreign Direct Investment in Semiconductors

David B. Yoffie

Semiconductors were a "global" industry long before the term was fashionable. Many U.S. semiconductor firms aggressively invested abroad prior to being well established in their home market. The rationale and location of foreign direct investment (FDI) in semiconductors largely fit conventional theories of foreign investment: at different points in time, firms located overseas to take advantage of low labor costs, to overcome tariff barriers, to appropriate their intangible assets (intellectual property), and to reduce transaction costs and arbitrage costs of capital differences. However, the patterns of investment have changed dramatically over the last two decades. This raises a number of interesting theoretical issues.

I will argue that FDI in semiconductors can be roughly grouped into three waves. During the first wave, in the 1960s and 1970s, the world leaders in semiconductors (largely U.S. firms) invested heavily overseas in assembly and test facilities which exploited locational advantages (low labor costs in Southeast Asia), and they only invested in fabrication facilities that jumped tariff barriers (in Europe). The Asian investment was complementary to trade; the European investment was largely trade substituting. For the most part, inward FDI did not occur in Japan because of strict capital controls.

During a second wave, in the mid-1970s, FDI moved beyond greenfield investment in the final stage of manufacturing to mergers and acquisitions of entire firms; European firms, in particular, expanded their presence in the U.S.

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market by buying U.S. companies. Acquisitions of non–start-up semiconductor companies in this second wave appear to have ended, at least temporarily, when political intervention prevented Japan's Fujitsu from buying a U.S.-based firm, Fairchild Semiconductor, which was owned by a French company, Schlumberger, based in the Netherlands Antilles.

A third wave of FDI started in the late 1980s and has continued into the early 1990s. This wave is characterized by significant FDI in greenfield front-end fabrication facilities, primarily by U.S. firms in Europe and Japanese firms in both the United States and Europe. With a few exceptions, most notably IBM and Texas Instruments (TI), core Research and Development activities on semiconductors have remained in the home base throughout the history of the industry.

The evolution of investment in these waves can be largely accounted for by political changes (e.g., the U.S.-Japanese Semiconductor Trade Agreement of 1986 and Europe's 1992 program) and changes in technology (i.e., declining labor intensity and rising scale economies). But the dynamics of change present some surprising puzzles. First, there has been stickiness to foreign investment in semiconductors. Despite radical changes in the economics of the industry, which largely negate the advantages of locating in low–labor cost countries, many historical investments in Southeast Asia have remained intact and been expanded. Second, there appears to be a lack of agglomeration in the new greenfield investments. While some theories might suggest that local externalities would produce investment in clusters (Krugman 1991; Porter 1990), significant portions of the greenfield FDI in the late 1980s and early 1990s have been widely dispersed in the United States and Europe. Third, there continue to be dramatic asymmetries between the style of investments by nonlocal firms in Japan and FDI in Europe and the United States. FDI in Japan is scarce, and the little investment which has occurred has been in the form of joint ventures, even though restrictions on FDI have been formally eliminated. Outside of Japan, by contrast, most Japanese and U.S. firms invest in wholly owned greenfield facilities outside of their home base.

The methodology for this paper relies heavily on relatively soft data and interviews. Unfortunately, systematic evidence on FDI in semiconductors is difficult to obtain: neither firms nor governments publish precise data on investment expenditures, overseas employment, or revenues. Even capacity numbers, which some firms disclose and which might be considered proxies for production, are unreliable because of variations in semiconductor yields. My primary source of data is from the industry, particularly Dataquest, which publishes plant locations, estimates of offshore production, and trade statistics. In addition, I have relied on interviews with managers in leading semiconductor firms in the United States, Japan, and Europe. The analysis is also confined largely to the merchant market for semiconductors and focuses primarily on the higher-technology, higher-growth segment of integrated circuits.

7.1.1 The Economics of Semiconductors—Past and Present

It is well known that semiconductors have some unusual economic characteristics. The production of semiconductors and, more specifically, integrated circuits (ICs) benefited more than any other product in industrial history from an amazingly steep learning curve. In 1964, a chip containing about sixty-four components was priced at around $32. By 1971, the price of a chip containing over a thousand components was about $1 (Yoffie 1987a; Borrus 1988). Between 1974 and 1988, there was a 635-fold reduction in memory prices per bit (Semiconductor Industry Association 1992). The rule of thumb in the industry was that costs generally fell 30 percent to 40 percent with every doubling in volume. Such steep learning economies occurred because semiconductor manufacturing routinely yielded more defective than sound chips. For complex new products, yields as low as 25 percent were quite common, while mature products might yield 90 percent. Although documentation is weak, producers also believed that there were intergenerational externalities: learning gained from making 1-Mb DRAMs, for instance, could be transferred to 4-Mb DRAMs.

In addition to learning economies, the semiconductor industry has been characterized by very high and growing economies of scale in front-end fabrication (fab) combined with extraordinary levels of research and development (R&D). In 1970, a minimum efficient scale plant required about $30 million in capital investment, and the output of that plant needed to generate roughly 3 percent of world sales to break even. By 1992, state-of-the-art plants cost an average of $650 million but could range from $200 million to as much as $1 billion; the cost varied with the complexity of the product and the desired volume. While overall world market share was no longer relevant, estimates suggested that a manufacturer would need $1.25 billion in annual revenue and 10–20 percent world market share within a particular segment to justify even a small fab.[1]

Also, unlike large, lumpy investments in other industries, which had long useful lives, physical plants became obsolete in only three to five years in the semiconductor business. There were several consequences of this economic feature. First, firms had to make significant ongoing capital expenditures.[2] Second, investments were generally sunk, with little or no after-market value. And a closely related third, the relatively thin market for capacity limited the options for FDI. Few firms wanted to buy competitors' fabs because of the rapid aging of the facility, plus variations in manufacturing processes between firms limited the general utility of any given firm's investment.

1. Interview with semiconductor executives.

2. While capital expenditures averaged only 10 percent of sales in 1990, they averaged over 30 percent in boom periods.

Beyond the economies of scale in manufacturing, semiconductors were also one of the most R&D-intensive industries, with R&D expenditures averaging more than twice the U.S. manufacturing average. In 1990, R&D was 12.8 percent of U.S. semiconductor revenues. Semiconductor technology also had a peculiar problem of being difficult to appropriate. Especially in the U.S. Silicon Valley, personnel tended to be highly mobile, and it was common for venture capital firms to lure away promising engineers from established companies. Most of the start-ups in Silicon Valley came from Fairchild and later Intel. The "leakiness" of technology and the significant infrastructure developed in Silicon Valley made it an attractive place for a new entrant to establish a business in the 1960s through the 1980s. At the same time, there were strong economies of agglomeration in R&D: very close coordination and communication among R&D facilities was desirable.

The cost structure of semiconductor firms has evolved over time. Variable costs, always small, have declined over the last three decades. The basic inputs into semiconductor production are sand (silicon) and electricity. Distribution and transportation costs are tiny (1–2 percent). By 1992, freight costs ranged from two–three cents for a commodity product packaged in plastic to ten cents for larger chips packaged in ceramic. With insignificant transportation costs, it was relatively simple in the 1960s and 1970s to physically separate the stages of production—especially fabrication versus assembly and test. By the 1980s, however, capital investment in automation dramatically reduced variable labor costs, virtually eliminating the cost penalty of colocating all stages of production in a high-wage location. A volume assembly facility in 1992 cost approximately $125 million–$130 million for the building (20 percent) and equipment (80 percent). One estimate suggested that direct labor per chip in 1992 was about ten–twenty cents in Southeast Asia versus twelve–fifty cents in the United States, depending largely on the product complexity.[3]

7.2 First Wave of FDI: Assembly and Test in Southeast Asia and Europe

The first wave of FDI in semiconductors was documented thoroughly by Kenneth Flamm (Flamm and Grunwald 1985). To summarize Flamm's argument, the first surge in foreign investment came in the 1960s from the pioneers in the industry, U.S. firms. The shift to offshore assembly operations became especially important between 1964 and 1972, driven by the aggressive moves of firms in the increasingly competitive industry to compete on cost. The natural division of production among wafer fabrication, assembly, and testing al-

3. Interview with industry executive. Since the final selling price of these chips could vary from $1 to $500, it is difficult to calculate direct labor as a percentage of sales. The assembly of the simple, low-priced memory chips, however, was much more automated. In addition, the added one–three cents in direct labor costs for simple chips in the United States could be offset by lower inventory costs.

lowed the assembly stage of production to be located at a different facility from fabrication without any significant impact on learning economies. And the assembly stage required relatively low-skilled labor that was available abroad at a substantial wage discount (as much as 90 percent), yielding up to a 50 percent reduction in total manufacturing costs. The difference in the final price of a chip could be as much as $1.50, versus $3.00 for memory products in the mid-1970s. Not for another decade could a high percentage of this labor cost be automated out of assembly.

The policies of both the United States and several newly industrializing countries also supported the offshore assembly strategy. Under items 807 and 806.3 of the U.S. Tariff Schedules as amended in 1963, imported articles assembled in whole or in part of U.S.-fabricated components became dutiable only to the extent of the value added abroad. This meant a substantial tariff break on the offshore assembly of chips. And beginning in 1967, the governments of Mexico, Taiwan, Singapore, Malaysia, and Korea established "export platforms" to encourage direct foreign investment. These platforms offered a wide variety of inducements to such investment, including tax-free exports, import tax reductions, and tax holidays. By 1974, the U.S.-based producers had established 136 operations overseas: 33 fabrication; 103 assembly, 69 of which were in developing countries in Latin America and Southeast Asia (see table 7.1). By 1978, more than 80 percent of the semiconductors shipped in the United States were assembled and tested overseas, mainly in these countries.

The second type of foreign direct investment—front-end fabrication to serve a local market—occurred mainly in Europe, where high tariff rates (17

Table 7.1 **Overseas Operations of U.S.-based Semiconductor Companies, 1974**

	Fabrication	Assembly	Total
North America	—	2	2
Canada	—	2	2
Europe	24	21	45
United Kingdom	9	7	16
France	5	3	8
Others	10	11	21
Latin America	1	24	25
Mexico	1	17	18
Others	—	7	7
Far East	8	56	64
Malaysia	—	14	14
Singapore	—	11	11
Hong Kong	—	11	13
Korea	—	9	9
Japan	6	—	6
Others	2	11	13
Total	33	103	136

Source: Finan (1975, 56–58).

percent of value), preferential procurement procedures, and pressure by the European governments (especially British and French) encouraged such investment to serve growing European markets. The first major period of investment in Europe occurred between 1969 and 1974, by which time 46 affiliates (18 engaged in complete manufacturing operations, including fabrication and assembly) had been established (Flamm 1990). In the absence of trade barriers, exports would have been the preferred mechanism for serving the European Economic Community market. The economies of scale in manufacturing and the added logistics costs of transferring designs and making the fabs "work" in Europe could only be justified economically if exporting was impossible. The least attractive option was to license technology to local firms. While cross-licensing was very common if two companies had patents that were mutually valuable, one-way licenses for money were less desirable because it was extremely difficult to appropriate adequate value from the technology.

Tariffs, quotas, and other forms of border protection also encouraged U.S. companies to consider foreign direct investment to serve the Japanese market. But the Japanese actively restricted such investment (in contrast to the Europeans, who actively encouraged it). The Japanese strategy was avowedly one of import substitution through the creation and promotion of indigenous suppliers, while the European strategy was one of import substitution, at least in part, through substituting the local production of U.S. companies for imports from them. Japan also restricted foreign purchases of equity in Japanese firms. High tariffs, restrictive quotas, and approval registration requirements were used to control imports. Approval was also required for all patent and technical assistance licensing agreements. As a result of controls on the acquisition of foreign technology, the Ministry for International Trade and Industry (MITI) acted as a monopsonist buyer of such technology and also controlled its diffusion among Japanese firms. These tight border controls held the U.S. share of the Japanese semiconductor market substantially below what it was in the rest of the world. By 1975, for example, U.S. firms had 98 percent of the U.S. market, 78 percent of the European market, and only 20 percent of the Japanese market.

The requirements posed by the Japanese government for investment were so unattractive that few firms chose to exercise this option.[4] Most leading U.S. firms chose the only avenue open to earn a return from the Japanese market: one-way licenses of technology. Through most of the 1970s, licensing fees amounted to almost 10 percent of Japanese sales (Braun and Macdonald 1982, 155). Only Texas Instruments (TI), by refusing to license its key integrated circuit patents to Japanese firms and by petitioning the U.S. government for trade protection based on patent infringement by the Japanese, was able to

4. Even after direct controls were abolished in 1978, non-Japanese firms found it difficult to invest in Japan.

Table 7.2 U.S. Participation in Foreign Semiconductor Markets

	Semiconductor consumption in France, Britain, W. Germany and Japan, Uncorrected Values ($ millions)	Percentage supplied by Direct Exports from the United States	Cumulative Number of U.S. Factories in These Countries	
			Assembly	Fabricating
1960	$134	11%	5	4
1961	151	15	6	4
1962	174	16	6	4
1963	208	17	7	5
1964	248	16	8	5
1965	323	23	8	6
1966	349	27	10	7
1967	390	32	11	7
1968	490	30	13	8
1969	660	37	24	15
1970	840	30	29	16
1971	875	25	30	18
1972	1,284	18	34	18

Source: Finan (1975, 120).

Note: Virtually 100 percent of U.S. supply to Japan was serviced by direct exports until 1970. And even TI's one local fab in Japan, jointly owned by Sony, did not have a material impaction these numbers through 1972.

extract permission from the Japanese government to establish a wholly owned manufacturing subsidiary in Japan in 1968.[5]

The implications this first wave of FDI had for international trade were unsurprising. Most FDI during this period was complementary to U.S. exports. Through the late 1970s, an estimated 80 percent of the fabrication by U.S. firms was still done in the United States; 20 percent was done abroad, mainly in Europe. The reverse numbers applied in assembly: about 80 percent of assembly by U.S. firms was performed abroad and only 20 percent at home. FDI in Europe, however, appeared to be largely a substitute for trade, at least during this early period. Direct U.S. exports to Europe declined between the late 1960s and the early 1970s, as the number of fabs more than doubled over a four-year period (see table 7.2). The combination of significant investment in assembly operations in Southeast Asia and investment in fabs in Europe reduced U.S. net export earnings, producing U.S. trade deficits as early as 1971 (table 7.3). Most U.S. imports until the late 1970s were assembled products

5. Initially, TI was only allowed to establish a 50–50 joint venture with Sony in 1968. Four years later, Sony sold out to TI. MITI finally agreed to TI's request for a wholly owned subsidiary only after TI threatened any Japanese exports of consumer electronics using TI's technology with an immediate patent infringement lawsuit. For more on the history of joint ventures in the semiconductor industry, see Steinmueller (1987).

Table 7.3 Total U.S. Semiconductor Trade ($ millions)

	Exports				Imports			
	Total	Integrated Circuits	Transistors, Diodes, and Rectifiers	Other*	Total	Integrated Circuits	Transistors, Diodes, and Non-Rectifiers	Other*
1966	$ 130.4	$ 8.9	$ 91	$ 30.5	$ 44.6		$ 28.7	$ 15.9
1967	152.4	26.5	81.4	44.1	46.5		26.7	19.8
1968	204.5	36.2	89.5	78.8	76.6		44.7	31.9
1969	345.7	72.4	138.6	134.7	111.2		59	52.2
1970	416.9	99.8	146.2	170.9	167.7	$ 69.4	59.8	38.5
1971	370.5	91.2	99.9	179.4	187	94.2	60.4	32.4
1972	469.6	103.5	126	240.1	328.8	180.5	100.1	48.2
1973	848.6	217.7	195.8	435.1	610.5	365.3	160.6	84.6
1974	1,247.5	313.5	215.6	718.4	953.5	606.3	235.9	111.3
1975	1,037	262.1	111.6	663.3	802	581.5	138.5	82
1976	1,385.9	320.4	120.3	945.2	1,098	813.7	153.1	131.2
1977	1,490.5	348.1	70.6	1,071.8	1,403.2	1,025	173.5	204.7
1978	1,521.4	471.9	85.4	964.1	1,827.4	1,405.2	179.1	243.1
1979	2,075.1	650.1	90.9	1,334.1	2,587.7	235.4	195	357.3
1980	2,782.3	833.5	95.2	1,853.6	3,395.6	2,780.4	212.2	403
1981	2,832.7	768.4	87.3	1,977	3,645.5	2,982.1	264	399.4
1982	3,058.9	836.3	81.8	2,140.8	4,397	3,501	263.9	632.1
1983	3,673.5	1,025.7	97.9	2,549.9	5,330.1	4,150.2	257.4	922.5
1984	4,651.5	1,391.3	118.8	3,141.4	8,284.2	6,125.8	345.9	1,802.5
1985	3,693.1	1,140.6	123.1	2,429.4	6,369.7	4,423.9	259.4	1,686.4
1986	4,185.4	1,148.1	138.8	2,898.5	6,685.7	4,539	303.7	1,843
1987	6,229	1,622.8	131.4	4,474.9	8,561.9	6,038.1	336.8	2,187
1988	8,035.4	2,588.5	168.4	5,278.5	12,089.8	8,767.6	452.2	2,896.9
1989	9,530.6				12,301.6			
1990	10,709.6				12,143.5			

Sources: 1966–72: U.S. Department of Commerce Publications #ES-2:15. 1973–76: U.S. Departmen of Commerce Publications #ES-2:17. 1977–82: U.S. Department of Commerce Publications #ES-2:19 1983–86: U.S. Department of Commerce Publications #ES-2:20. 1987–88: compiled from U.S. Department of Commerce Publications #FT-246. 1989–90: Compiled from U.S. Department of Commerce statistics (breakdowns for 1989–90 were not available due to a change in classification from SIC to a harmonized system).

*Other semiconductor devices.

from U.S. affiliates located in the newly industrializing countries (NICs). U.S. exports of unfinished circuits were primarily to five Southeast Asian assembly locations for final assembly and packaging. These products were then either reexported to the United States or to Japan and Europe.

The one other area where FDI might have been trade substituting was TI's fab investments in Japan. TI's strategy was to service the Japanese market from its facilities in Japan. By the 1980s, even TI had become a net exporter from

Japan, importing virtually nothing from the United States.[6] While its initial investment might have been considered a complement to trade (since MITI strictly limited TI's imports), TI did not switch production back to the United States when imports restrictions were liberalized in the mid-1970s.

7.3 Second Wave: European Acquisitions of U.S. Firms

From the mid-1970s through the mid-1980s, the structure of the semiconductor industry changed, and so did the patterns of direct investment. The most obvious structural shift was the rise of Japanese competitors, accompanied by the virtual collapse of Europe and the relative decline of U.S. firms. Here again, the story is well known and need not be repeated in this paper. But accompanying this structural shift in competitive position was a change in investment patterns. FDI in assembly facilities in Southeast Asia continued and indeed expanded as Japanese firms also began investing in assembly operations in the region. There was also further incremental U.S. investment in fab capacity and design centers in Europe and Israel.[7] However, the most notable trend in FDI during this period was outright acquisitions or taking substantial ownership positions in leading U.S. firms.

A list of the major corporate acquisitions or investments can be found in table 7.4. Most of the explanations for these investments fit into the school of industrial organization motivations for FDI rather than the variety of macroexplanations associated with locational advantages, tax policies, cost of capital, protectionism, and so on. It is hard to attribute the trend to macroeconomics or macropolicies, because the pattern of acquiring U.S. semiconductor companies was so ubiquitous: the investors were large U.S. companies as well as non-U.S. firms based in a variety of locations in Europe, North America, and Asia. Although a few of the acquisitions could be traced to firms trying to diversify their existing business portfolio, such as Exxon's purchase of Zilog and Schlumberger's purchase of Fairchild, most of the acquiring firms were already in some part of the electronics business.

Until the end of the 1970s, small U.S. firms were the clear leaders in product and process technology. Many of these companies were willing recipients of foreign (or domestic) capital because of the rising capital and R&D expendi-

6. Interview with TI executives, 1986.

7. Israel was unusual because it was probably the only country where U.S. firms, such as Motorola and Intel, invested in R&D facilities that served the global market. The design centers in Israel, unlike most Japanese design centers in the United States or U.S. design centers in Europe and Japan, were not exclusively focused on local adaptation of products. Two firms, National Semiconductor and Intel, also invested in fabs in Israel. Israel was an attractive location because the government offered tax relief and some subsidies in addition to an abundant supply of highly qualified engineers and preferential tariff treatment for Israeli exports to Europe. Intel's decision to invest in a design center and then a fab was largely a consequence of a senior, highly valued Intel manager who wanted to return home.

Table 7.4 Selected Corporate Investments in U.S. Semiconductor Companies, 1975–1991

Date	U.S. Company	Corporate Investor	National Base	Equity Ownership (%)
1975	Maruman IC	Toshiba	Japan	100%
1975	Signetics	Philips	Netherlands	100
1976	Advanced Micro Devices	Seimens	West Germany	20
1976	American Microsystems	Robert Bosch	West Germany	12.5
1976		Borg Warner	United States	12.5
1976	Interdesign	Ferranti	United Kingdom	100
1976	Monolithic Memories	Northern Telecom	Canada	24
1976	MOS Technology	Commodore	Bahamas	100
1977	Exar	Toyo	Japan	53
1977	Frontier	Commodore International	Bahamas	100
1977	Intersil	Northern Telecom	Canada	24
1978	Electronic Arrays	Nippon Electric	Japan	100
1979	Fairchild	Schlumberger	Netherlands Antilles	100
1979	Inmos	National Enterprise Board	United Kingdom	
1981	Advanced LSI Logic	Micrel	United States	
1985	Storage Semiconductor	California Devices	United States	Plants
1985	Storage Semiconductor	Zoran	United States	Plant
1986	Micron Technologies	Samsung	South Korea	22
1986	Comdial Technology	Orbit Instrument Group	United States	80
1987	Fairchild/Schlumberger	National Semiconductor	United States	100
1987	Monolithic Memories	Advanced Micro Devices	United States	Merger
1987	GTE's Comm Sys Division	California Micro Devices	United States	Microcircuits division

1988	AT&T	Silicon Systems	United States	Plant
1988	Zymos	Daewoo	South Korea	51
1988	GE Solid State Semicon	Harris	United States	100
1988	Honeywell Colorado Chip	Atmel	United States	100
1988	Micron Technologies	Amstrad PLC	United Kingdom	9.8
1988	Zoran	Synergy	United States	Plant
1988	Zymos	Saratoga	United States	Plant
1989	Silicon Systems	TDK	Japan	Plant
1989	Saratoga	Maxim	United States	Plant
1989	Vitelic	Oki Electronic	Japan	Minority stake
1989	Data General	Rohm	Japan	Plant
1989	Honeywell Solid State Division	Atmel	United States	Electronics division
1990	GegaBit Logic	Cray Computer	United States	Fabs
1990	Cypres Semiconductor	Altera	United States	Plant
1991	Tera Microsystems, Inc.	Mitsubishi	Japan	6.7
1991	Vitelic	Mosel	United States	Merger
1991	VTC	Cypress	United States	Plant
1991	Crystal Semiconductor	Cirrus Logic	United States	100
1991	Gigabit Logic	Triquint	United States	Merger

Source: The Wall Street Journal (various issues); *New York Times* (various issues).

tures required in the industry. While venture capital was plentiful for most of this period for start-up companies, intense Japanese competition beginning around 1976 limited access to debt and equity markets for small firms that wanted to expand their fab or assembly operations. Prevailing wisdom at the time was that a large, diversified parent corporation could solve the inherent cyclicality problems of the business.

If small U.S. firms were willing to be acquired, why did large European, some large Japanese, and even South Korean companies want to buy?[8] The answer has two parts. First, several of the acquired companies had significant technologies, patents, or cross-licenses. Even for firms not in the merchant semiconductor market, integrated circuit technology was perceived to be critical for downstream applications. There was a variety of externalities associated with ICs. As chips became more highly integrated, growing in capacity and complexity, they took on the characteristics of entire systems. To appropriate the value of the system, most major computer, telecommunications, and consumer electronics companies in the world believed that they would have to make semiconductors. Companies such as IBM, DEC, Hewlett-Packard, Siemens, and Philips, as well as all of the large Japanese electronics companies, integrated backward in the 1960s. In fact, several of these companies, particularly IBM and DEC, gained significant competitive advantages from their ability to design and make custom logic chips that were proprietary.

A second rationale behind these acquisitions was to learn the "secret" of U.S. success in semiconductors. For European firms in particular, partly because they had failed to become significant players on their own, acquiring or investing in small U.S. companies was attractive. Europe was a relatively small and fragmented market for semiconductors, compared to the United States, in the early 1970s. Dominated by national champions, none of the large European semiconductor manufacturers had established itself in a position of global leadership. By investing in U.S. companies, many of which had at least one generation of successful products, these European firms hoped to appropriate some of the externalities of being located in the leading market for innovations in semiconductors. Silicon Valley in California was an especially attractive region because of the leakiness in technology and mobility of personnel. As one European scholar reported from an interview with European semiconductor executives,

> Such a firm [the European acquisition] would rapidly discover what ingredients contributed most to success in the industry, would act as a training ground for non-American personnel and would be able to funnel information about processes and techniques to the parent firm or home country with

8. Korea's Samsung bought 22.1 percent of Micron Technology, a DRAM manufacturer, for $5 million in 1986. This particular horiozntal investment seemed to be targeted at getting across to DRAM patents and technology. Also in 1986, Daewoo bought controlling interest in a small semiconductor firm, Zymos, in a bid to enter semiconductors ("Overseas investments" 1991).

the minimum delay and the maximum effectiveness. (Braun and Macdonald 1982, 175–6)

None of the acquisitions, however, proved to be profitable for foreign (or even domestic) acquirers. Without exception, the European acquisitions were unsuccessful. Siemens, unable to gain leverage in its investment in Advanced Micro Devices, divested its holdings in 1991; American Microsystems, partly owned by Germany's Robert Bosch, no longer exists; Interdesign was absorbed by Ferranti, which remained a minor player in semiconductors; and Inmos dropped in market share to obscure levels. In the early 1980s, France's Thomson Semiconductor merged with Italy's SGS, which in turn bought Mostek from ITT. In the mid-1970s, Mostek was a significant DRAM supplier. By the late 1980s, Mostek facilities and product lines had virtually disappeared.

But the greatest failure of them all was Fairchild Camera, one of the pioneers of U.S. semiconductors. From the outset, Fairchild proved to be a cash drain for its parent, Schlumberger. Schlumberger entered a bidding war with a U.S. firm, Gould, for Fairchild in 1979. As a white knight, it paid $425 million in cash, which included $253 million in goodwill. Over the next seven years, Schlumberger invested another $1 billion in capital additions and research and development. While no public information on the profitability of Fairchild was ever released, Schlumberger accumulated for tax purposes net operating loss carryforward provisions of $600 million by 1986.[9] Prompted by these deep losses as well as a dramatic erosion in market share (Fairchild dropped from number two in the world in 1975 to number fourteen in 1985), Schlumberger tried to sell 82 percent of Fairchild to Fujitsu in 1986. The price was $225 million, but Schlumberger would keep the most valuable asset: the $600 million in tax losses. However, in the wake of several dumping suits filed against Japanese producers, U.S. Commerce Secretary Malcolm Baldrige opposed the sale. Five days after the secretary went public with his opposition, Fujitsu withdrew its bid. Six months later, Schlumberger sold all of Fairchild to a U.S. company—National Semiconductor—for $122 million.

Foreign and military policy considerations continued to stall foreign acquisitions of U.S. semiconductor companies. In 1987, the United Kingdom's Plessey sought to buy Harris Semiconductor, a manufacturer that focused almost exclusively on the government market, particularly military applications. When the Pentagon threatened not to buy chips from firms owned by non-U.S. capital, that deal also fell through (Ziegler 1991). Harris remained independent and a few years later expanded its semiconductor operations by buying General Electric's captive semiconductor subsidiary.

The Fairchild-Fujitsu deal was clearly the turning point for foreign acquisitions of non–start-up companies in the United States, especially from Japanese suitors. Fujitsu, which had no semiconductor investment in the United States

9. This brief discussion of Fairchild relies on MacKenzie de Sola Pool (1988); Rukstad and Wolfson (1989).

prior to 1986, was willing to pay a premium for Fairchild because Fairchild offered a strong patent position (dating back twenty years) that could give Fujitsu an entrée into new markets, especially U.S. defense markets. In addition, for the price of one fabrication facility, Fujitsu would have a base in the United States from which to expand and at least some of Fairchild's accumulated experience of working in Silicon Valley.[10] At a time of excess capacity in the industry, no U.S. firm could place a similar value on Fairchild's intellectual or physical assets. In the absence of political intervention, more such acquisitions might have been predicted. As discussed below, political events of the mid-1980s made locating fabrication in the United States suddenly more attractive for Japanese firms. However, Japanese firms seemed to have viewed the Fairchild incident and, to a lesser extent, the Harris decision as a signal that the U.S. government would prevent or forestall wholesale acquisitions of leading U.S. semiconductor companies. Acquisitions of very small (usually fabless) semiconductors have continued (see table 7.4), but unlike many of the earlier investments in U.S. capacity and market position, these investments have largely been purchases of technology.

7.4 Third Wave: New Greenfield Investment in Fabrication Facilities

The first wave of FDI was largely outflows from the United States, driven by the labor intensity of semiconductor assembly and the protectionism in Europe; the second wave of foreign acquisitions was largely European firms, driven by their failure to establish a successful base at home.[11] Throughout these periods, however, Japanese firms remained insignificant exporters of long-term capital. Prior to 1990, most large Japanese firms had assembly plants in Southeast Asia for very price-sensitive commodity products, but only four firms had fabrication plants outside of Japan, all (five fabs) in the United States and none in Europe. According to Dataquest, in a $60 billion worldwide market in 1989, Japanese companies accounted for more than 45 percent of world revenues but only 16 percent of the world's $6 billion in offshore production (Dataquest 1990).

Three events in the mid-1980s should have stimulated a renewed interest in FDI by all major players. Two events were political: the U.S.-Japanese Semiconductor Trade Agreement and Europe's 1992 program. The 1986 semiconductor trade agreement (hereafter referred to as the SCTA) was critical in enticing Japanese factories to the United States, while fears over the possibility of

10. At least some management could be expected to stay, since the deal with Schlumberger would have offered senior management an equity stake that would grow over time.

11. Some European firms continued to use an acquisition strategy. Phillips had the most success with its U.S. acquisition of Signetics. Philips was the only European to remain a top-ten semiconductor firm in 1991. While it was not believed to be a very profitable operation, it continued to make significant investments, including a majority ownership in Taiwan Semiconductor Company in 1989.

fortress Europe in 1992 encouraged both Japanese and U.S. companies to expand their presence within Europe. The third event was Japanese firms taking leadership in certain commodity products and, more important, Japan becoming the largest market for semiconductors in the world in 1986 with many of the world's leading semiconductor equipment vendors (USITC 1991). On the surface, FDI would have seemed more attractive, since Japan's market was now officially open. Japan consumed 50 percent of world production after 1986, and the SCTA sought to guarantee U.S. and other non-Japanese firms 20 percent of that market.

The SCTA was obviously important in stimulating Japanese investment in the United States because of its pricing provision. Immediately prior to the SCTA, the U.S. government found Japanese companies guilty of dumping DRAMS and EPROMs (another type of memory), with dumping margins of up to 188 percent for individual Japanese suppliers. As part of the SCTA, the United States agreed to suspend the dumping suits in exchange for the Japanese producers agreeing not to sell their products at prices below their (average) cost of production, plus an 8 percent profit margin, in the United States and third markets. The United States reserved the right to add or drop products from the monitoring arrangement in the future. It was anticipated that this arrangement would deter or prevent dumping of such products in the future. However, products manufactured in the United States would be exempt from the pricing guidelines.

Changes in European rules of origin on semiconductors provided similar incentives for FDI in Europe. In 1989, the commission fundamentally altered the definition of "made in EC."[12] Prior to 1989, chips would be considered European if the "last substantial process or operation that is economically justified was performed" in the EC. Assembly and test operations were counted as a "substantial process" under these guidelines. The new rules, however, stated that fabrication of wafers or diffusion was necessary to exempt the chips from duty. This change also influenced the antidumping rules in the EC. In the past, a manufacturer could move test and assembly to the European Community and be exempt from possible dumping sites. Since Japanese and Korean firms had been frequent targets of dumping suits in the electronics industry, the EC regulation was widely interpreted as an "antiscrewdriver" plant rule targeted at Asian producers.[13]

The combination of these two policy changes in Europe and the United States influenced a step-function change in the policies of Japanese firms toward FDI. By 1990, virtually every Japanese firm had announced plans for new facilities: eleven (ten of which were memory) were slated for the United States, and ten (eight memory) were proposed for Europe. In my interviews

12. Quoted from EC Regulation 802/68, article 5, in Flamm (1990, 271).

13. One Korean firm, Samsung, also invested in fab capacity for DRAMs in France. Since Samsung has excess capacity at home, politics can be the only explanation for this investment.

with Japanese firms, their managers argued that "in terms of costs, management of engineers, and the control of production, it was better to produce in Japan."[14] Nonetheless, these firms decided to invest abroad. The rationale most frequently cited for this decision was trade friction, but there were also other familiar rationales such as "being close to the customer," access to new engineering talent and technology, and access to foreign capital. Moreover, the pattern of investment by firms had striking parallels to Knickerbocker's hypothesis that smaller companies in oligopolistic industries often follow the industry leader overseas (Knickerbocker 1973). In semiconductors, the largest Japanese producer, NEC, pioneered investment in the United States in the late 1970s and was the first to invest in Europe (Scotland and later West Germany). The other large semiconductor firms—Hitachi, Mitsubishi, Matsushita, Toshiba, and Fujitsu—lagged a decade behind NEC in the United States but only two to three years behind in Europe. Smaller firms (e.g., NMB) generally eschewed building foreign fabrication facilities. In at least two instances, Japanese firms did buy existing capacity: Matsushita's production in Oregon was a small fab bought from National Semiconductor as part of the Fairchild acquisition, and Sony made a deal with AMD in the United States to have use of their fabs in Texas for making static RAMs. AMD, financial strapped, later sold Sony the capacity. The former AMD fab had forty times more capacity for SRAMs than Sony's 1991 semiconductor market share in the United States.

Few of the Japanese investments in the United States or Europe could be easily justified by strictly economic criteria.[15] The economics of production was the driving force behind the first wave of assembly FDI in Southeast Asia; the desire to appropriate some of the spillovers of semiconductors was the driving force behind the second wave of acquisitions. In this third wave, only the sale of some semiconductor products, particularly application-specific integrated circuits (ASICs), could benefit from closer links between the customer and the manufacturing location. All of Toshiba's U.S. operations, for instance, were small, "personalization" fabs that took mostly finished wafers from their Japanese factories and performed the final two or three (out of two hundred–plus) steps of production in the United States. They were relatively small investments for the purpose of local customization.

Politics was the driving force behind the vast majority of Japanese FDI in fabrication for memories, particularly DRAMs and SRAMs. Since these products were strictly commodities with huge economies of scale and virtually zero transportation costs, the best location for a DRAM plant was next to the R&D lab. Yet virtually all of the significant R&D for memory products of Japanese firms was kept at home.[16]

14. Interviews with Japanese firms, December 1989.

15. Toshiba, for example, announced plans to build fab capacity in Europe after the change in regulations but subsequently decided to postpone it indefinitely. They announced in 1991 that further new capacity could not be financially justified. Interview with industry executive, 1992.

16. It was common practice in the semiconductor industry for firms to have design centers in major markets. Japanese firms were no exception to this rule. Design centers, however, were not a

Another important attribute of Japanese fabs in the United States was that they were generally not using state-of-the-art technology in 1992. In Japan, the newest memory fabs used eight-inch wafers and 0.5-micron line width technology: the most advanced Japanese fab (NEC) in the United States had six-inch wafers with 0.7-micron line width; the majority of the fabs averaged around 1.0-micron line width.[17] Several of the plants in the United States (not including NEC, Hitachi, and Fujitsu) were built and equipped for under $100 million, suggesting they were largely pilot operations for small-volume business. NEC, which entered the market in 1978, was the only Japanese firm operating at very high volumes. The other leading Japanese firms had not fully ramped up production in the United States. In Europe, by contrast, most Japanese firms had committed bigger investments ($200 million–$400 million) in capital for large-scale memory production with six-inch wafers at 0.8-micron line widths.

There was a similar pattern, on a much smaller scale, of expanding fabrication facilities by U.S. companies in Europe. Since most U.S. semiconductor companies already had fabrication facilities in Europe, further FDI would only be likely if a firm needed to expand capacity for the European market. Excluding IBM, which entered a joint venture with Siemens in France for advanced memories, Texas Instrument was making the largest investment, with $1.2 billion, four-year project in Italy with heavy Italian government subsidies, including grants and loans. Three other U.S. firms decided to invest for the first time in Europe in the late 1980s and early 1990s: Intel, AT&T, and Analog Devices. Intel and Analog Devices built fabs in Ireland; AT&T built a large semiconductor fab in Spain. Among all U.S. semiconductor firms, only TI and IBM did significant R&D in Europe.

Despite what appeared to be obvious incentives for U.S. and European manufacturers to invest in Japan in the late 1980s, the rate of non-Japanese fab investment in Japan was virtually unchanged from the earlier periods. Point-of-sales affiliates, design centers, quality assurance and testing centers, and failure analysis centers expanded by more than a factor of two after the SCTA (Semiconductor Industry Associations 1989). None of these facilities, however, required significant capital investment. Prior to the SCTA, only four merchant "American" semiconductor companies (TI, Motorola, Fairchild, and LSI Logic) had fab or assembly facilities in Japan, but Schlumberger sold off Fairchild's Japanese fabs and only TI and Motorola expanded after 1986.[18] LSI Logic, an ASIC vendor with under $1 billion in revenue, located its first fab in

significant portion of total R&D spending for any semiconductor firm. Rather, a design center would take core products that came out of centralized R&D and adapt them for local needs. Sharp, for instance, built what it described as an R&D center in Washington State; however, the R&D was virtually all final-stage customization for the U.S. market.

17. Interview with industry executives, 1992.

18. This excludes IBM and AT&T. IBM had semiconductor facilities in Japan dating back twenty years, and AT&T entered into agreements with NEC on semiconductor technology in the latter half of the 1980s.

Japan. LSI needed capital, and Kawasaki Steel, looking to diversify, was willing to underwrite most of the investment ("A new emerging species" 1991).

Motorola entered the Japanese market after liberalization of capital controls in 1980. It went into a joint venture with a failing Japanese semiconductor company, (Aizu-Toko), which Motorola subsequently bought in 1982. After exiting from DRAMs in 1985, Motorola licensed some of its key microprocessor technology to Toshiba as part of a joint manufacturing in DRAMs in 1986. The joint venture also called for Toshiba to help Motorola with market access in Japan. (Motorola subsequently invested in a small fab in China in 1990 to serve the Chinese market, as well as new assembly test facilities in Hong Kong.)

TI adopted an aggressive strategy of new FDI in fab capacity in the late 1980s and early 1990s. While TI planned $2 billion in capital expansion, 50 percent of that investment was to be underwritten by foreign partners. In addition to its deal in Italy, TI planned to expand DRAM capacity in Japan, Singapore, and Taiwan. TI's major commitment of capital in Japan was done with a joint venture with Kobe Steel; in Taiwan, it was done with a joint venture with a PC clone company, Acer Computer. The Singapore joint venture included Canon, Hewlett-Packard, and the Singapore Economic Development Board, which collectively would invest $330 million for a facility to open in 1993.

FDI by European competitors was nonexistent in Japan in the latter half of the 1980s, while FDI in the United States was in a disinvestment mode: SGS-Thomson built a shell for a fab in the early 1980s in Phoenix but had not filled the building with equipment through 1992; Philips-Signetics was scaling back its operations, exiting from its older fab in Salt Lake City while retaining its plant in New Mexico; and Siemens had a very small pilot fab in Silicon Valley for sale.

7.5 Some Consequences of the Recent FDI

If one looks at the total FDI fab capacity invested in semiconductors in Europe, Japan, the United States, and developing countries in the 1980s, only U.S. investment in Europe significantly altered the global configuration of production of trade. As noted earlier, only an estimated 10 percent of world production took place outside of national firms' home bases by 1989 (see figure 7.1). Production was clearly "global," in the sense that products continued to be shipped to Southeast Asia for finishing and then reexported to the home and third countries. But by 1990, as figure 7.2 illustrates, Japanese firms had less than 4 percent of the fab lines in the United States and 3 percent of Europe, while TI and Motorola had only 8 percent of the lines in Japan.[19] The most

19. Fab lines are probably the most accurate measure of activities by nonlocal producers, but they do not equate to share of production. The Japanese had roughly 46 percent of world production in 1990 but only 29 percent of the semiconductor fab lines, because they have a narrower range of product offerings than do U.S. firms and larger, dedicated lines that produce higher volumes of chips than the average of U.S.-owned line.

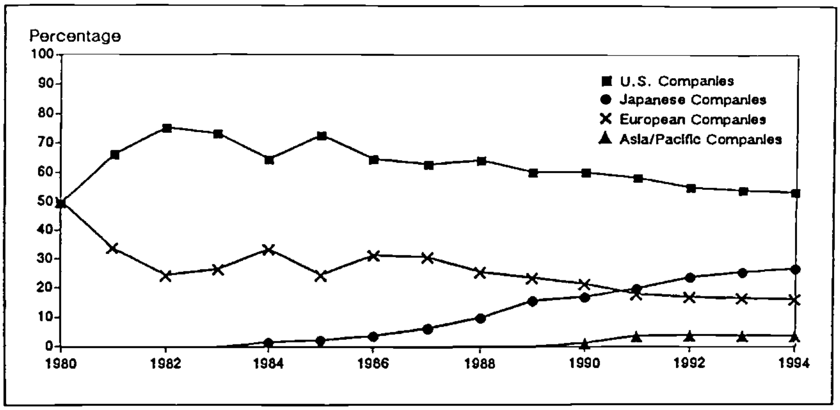


Fig. 7.1 Percentage of total offshore production by regional companies
Source: Dataquest (1990).

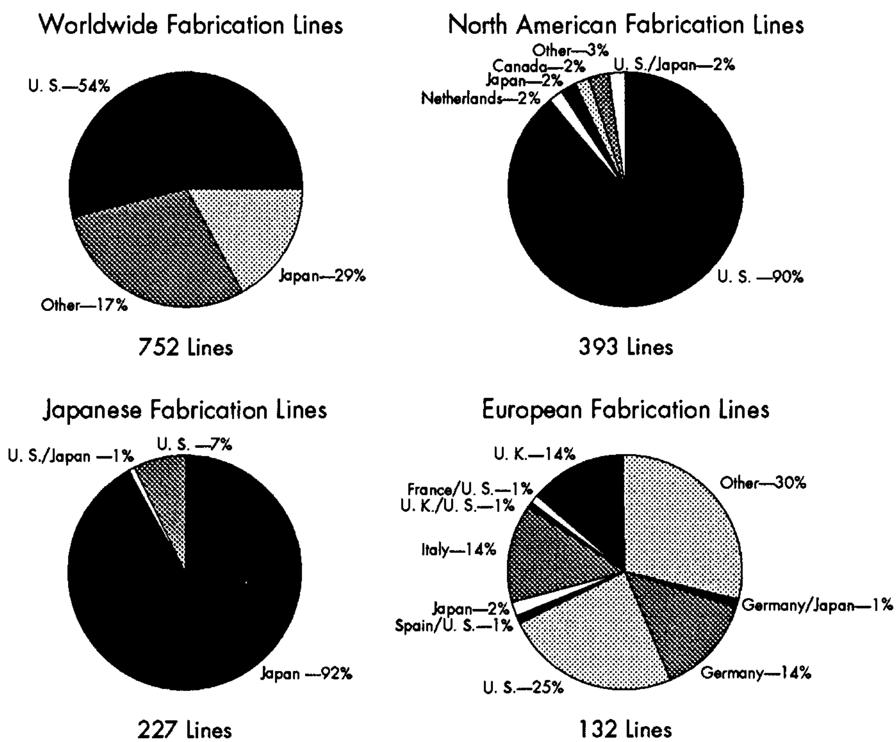


Fig. 7.2 Semiconductor fabrication lines: Location and ownership by major market and principal producers' share, 1990
Source: Semiconductor Equipment and Materials International.

Table 7.5 **Total Japanese Semiconductor Trade ($ millions)**

	Exports		Imports	
Year	Integrated Circuits	Total	Integrated Circuits	Total
1967[a,b]		$ 16.6	$ 5.0	$ 17.0
1968[b]		18.7	12.0	27.5
1969[b]		27.1	21.8	47.7
1970[b]		27.2	57.4	92.5
1971[b]		27.9	69.6	89.8
1972	$ 6.8	42.0	54.2	81.3
1973	9.5	84.3	122.5	181.8
1974	22.9	130.8	154.7	206.3
1975	45.5	140.8	134.9	182.9
1976	76.7	236.0	199.4	280.7
1977	117.9	309.4	207.6	291.7
1978	248.2	480.4	291.4	378.0
1979	494.5	753.8	449.6	556.2
1980	808.8	1,087.6	480.3	609.3
1981	904.9	1,236.5	517.8	686.7
1982	1,144.8	1,425.9	511.4	641.2
1983	1,784.2	2,150.0	642.4	785.9
1984	3,271.2	3,778.3	935.6	1,137.4
1985	2,439.7	2,920.9	693.8	836.3
1986	3,107.4	3,797.3	867.7	1,026.2
1987	4,096.6	5,005.4	1,125.4	1,307.6
1988	6,598.3	7,915.4	1,761.0	2,003.1
1989	8,313.0	9,681.1	2,246.9	2,547.0
1990	7,595.1	9,005.4	2,589.1	2,921.3

Source: Japan Electronics Bureau, JETRO.

[a]During the 1965–66 period, the Japanese exported only discrete semiconductor devices (DSDs); these included germanium transistors, silicon transistors, germanium diodes, silicon diodes, and silicon diodes for silicon rectifiers. (Thus, the data do not include integrated circuits for this period.)

[b]In the 1967–72 period, the Japanese began exporting integrated circuits (ICs). However, the data do no distinguish between ICs and DSDs.

material consequence of FDI has been felt in Europe, where U.S. firms had 25 percent of the total fab lines in production in 1990.

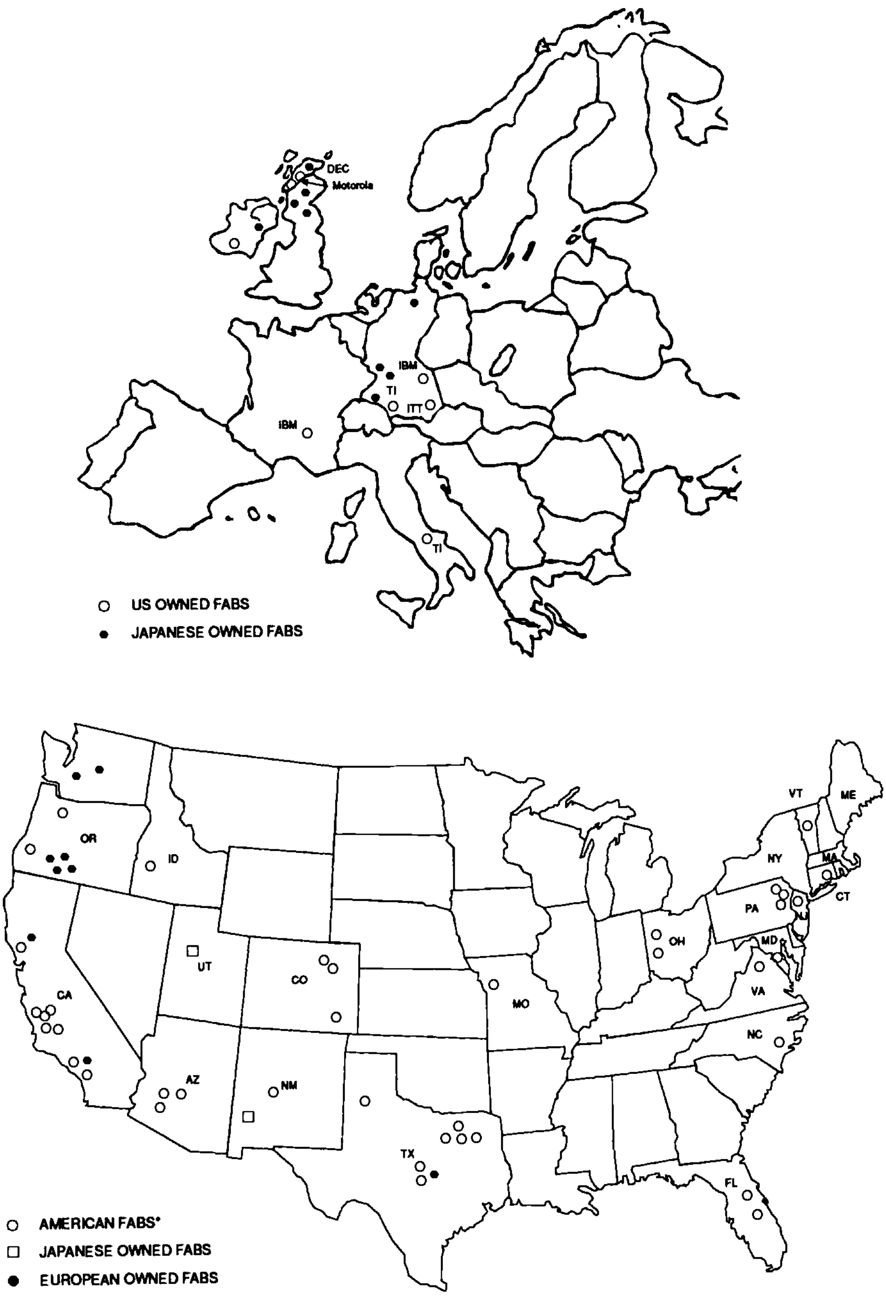
The implications of FDI in the 1980s and early 1990s had for trade and employment were relatively modest. Japanese firms continued to serve world markets largely through direct exports from Japan: the 10 percent decline in Japanese semiconductor exports in 1990 (table 7.5) was a result of collapsing DRAM prices, not trade substitution. Due to the limited ramping of U.S. production by Japanese fabs, Japanese imports were 82 percent higher in 1990 than in 1986. In the meantime, the United States continued to run trade deficits in semiconductors, but the bulk of imports into the United States—on the order of 65 percent to 70 percent—still originated from the foreign subsidiaries of U.S. companies.[20]

7.6 Implications of FDI in Semiconductors

There appear to be three possible anomalies in the evolving pattern of FDI in semiconductors. First, there has been a stickiness to FDI in semiconductors that is not purely economic in nature. Many U.S. firms invested aggressively in assembly and test facilities in Southeast Asia during the 1960s and 1970s. The impact of these historical investments continue to weigh heavily on the industry in the 1990s. If the semiconductor industry had started in this decade, with Japanese and U.S. firms holding the same competitive positions they held in 1990, the structure of world production would be vastly different. The volume of products shipped from Southeast Asia would be substantially reduced; direct U.S. exports would be much greater; and facilities in Ireland, Scotland, Israel, and various locations on the European continent might not even exist. Instead, most firms have, over time, expanded facilities in old locations, particularly in Southeast Asia. For the most part, organizational inertia appears to be the best explanation. Remember that only the physical plant, which accounts for about 20 percent of the capital costs of an assembly/test operation, is sunk: the equipment (80 percent of total costs) is mobile, and in the late 1980s and early 1990s, locating assembly and test next to the fabrication plant was more cost effective. Local assembly was especially cost effective for higher value-added logic products, which were increasingly dominating U.S. companies' product lines.

The second anomaly that appears in the data is the location of new FDI in fabrication facilities. The history of domestic investment in semiconductors in the United States and Japan clearly exhibits a clustering phenomenon: U.S. fabrication and R&D facilities clustered around three locations: California's Silicon Valley, Phoenix (Motorola's semiconductor headquarters), and Texas (TI's headquarters). In Japan, a similar clustering took place in the corridor between Tokyo and Yokohama and around Osaka. There was less clustering in Europe because of sovereign national boundaries. However, if one looks at the pattern of FDI in both the United States and Europe since the mid-1980s, investments have been widely dispersed. In Europe, new facilities have been built in Ireland, Scotland, England, Spain, Germany, Italy, France and (if one considers Siemens's non-German European investments) Austria (see figure 7.3). In the United States, Japanese FDI has gone to Washington, Oregon, and

20. One estimate by industry executives suggested that Japanese firms were producing roughly $1.5 billion worth of ICs in the United States in 1991, compared with roughly $5 billion in annual U.S. sales and $3.5 billion in imports. However, if the Japanese fully ramped their existing capacity in the United States, they could substitute more than half their exports for domestic production. Interview with industry executives.



* Sematech Members

Fig.7.3 Location of FDI: United States and Europe, 1991

North Carolina, as well as to established clusters in Texas, California, Arizona, and New Mexico.[21]

There are at least two complementary explanations for these location decisions. First, and probably most important, there has been significant competition for FDI among states in the United States and even more intense competition among nations in Europe. Given the heavy capital intensity of fab investments, a variety of benefits—direct subsidies, interest-free loans, tax relief, free or subsidized land, and so on—provided by local governments have made some locations more attractive than others for investing firms. When the industry was in its infancy, subsidies in many instances would not have outweighed the benefits of clustering. Skilled labor was in short supply, and it was easier to hire those workers in established clusters, where they had more abundant job opportunities. The availability of the necessary infrastructure for constructing a complicated fab and a guaranteed power supply were also critical.[22] However, most of these inputs were available in the 1990s in many developed countries and most U.S. states. As a result, those specific benefits or positive externalities of clustering are less obvious to firms.

Second, some managers have interpreted the leakiness of semiconductor technology as a negative externality, which can be minimized by locating in places outside of existing clusters.[23] While countries and states are explicitly trying to replicate the dynamism of Silicon Valley by attracting foreign capital, firms are trying to avoid the negative consequences of Silicon Valley: the risks associated with state-of-the-art process and product technology leaking to competitors with facilities in the region. Building a fab in a new location does not guarantee that other firms will not locate there in the future, but there is a relatively low probability that a Spanish or Irish fab worker will end up in a competitor's factory in France or Germany. If firms continue to disperse their foreign investment activities and limit the scope of their foreign operations, the return on government subsidies for attracting FDI could be low indeed.

There also appeared to have been differences between the locational strategies of Japanese and U.S. firms. There is no dominant choice for a location within Europe, because demand for products is spread broadly across many European nations. Nonetheless, U.S. firms were more likely to be influenced by the size of the subsidy than were their Japanese counterparts. The biggest subsidies were offered by Spain, Ireland, and Italy, which enticed AT&T, Intel, and TI, respectively. NEC located in Scotland (large fab) and West Germany (small fab), while Fujitsu located in England. Japanese managers' greater comfort with English might be part of the explanation. Both regions offered financial incentives, though apparently much less than competing locations.[24]

21. Intel established a fab in New Mexico in the early 1980s.

22. Even minor power outages can be devastating to a semiconductor fab: a momentary outage can ruin up to $200,000 of work-in-progress per incident.

23. This insight came from interviews with managers of one U.S. firm's European operation.

24. Interview with industry executives.

Hitachi also opted to invest in West Germany, despite very limited government support.

A third anomaly, one difficult to explain, is the lack of significant new greenfield FDI in Japan; also, the little FDI which has taken place is almost exclusively in the form of joint ventures, despite fourteen years of "liberalized" capital flows. The primary driver behind FDI in Europe was the perception that, without a local presence, the market might become closed to Japanese and U.S. companies. A similar logic might have been applied to Japan, assuming that one believes being located behind any external barriers creates greater opportunity for sales. Japan, however, should have been a much more attractive market for FDI than Europe. Japan being the world's largest market for semiconductors, with much of the world's most advanced equipment suppliers, one might predict that non-Japanese firms would want to invest to take advantage of the externalities associated with local semiconductor production.

Some traditional explanations for the lack of FDI, such as the weak market for corporate control, cannot explain the lack of semiconductor FDI in Japan. Motorola, for example, was able to buy a Japanese firm to enter the market in the late 1970s. In addition, there is a market for fab capacity in Japan, even without buying an entire firm. High land prices in Japan have also been cited as a deterrent to entry, but some firms (e.g., Intel) who purchased adequate land in Japan more than a decade ago have still opted against FDI in fabrication or assembly. Moreover, joint ventures appear to be the dominant form of investment, even for firms with experience in Japan. Since the SCTA also gave Japanese firms additional incentives to buy non-Japanese semiconductors—up to 20 percent of the market—there were even greater incentives for FDI.

Without direct government subsidies or other benefits available to foreign investors in Europe or the United States, managers of U.S. and European firms continue to believe that the externality benefits of FDI in Japan do not offset the cost penalties associated with recruiting high-quality labor and the general high cost of operations in Japan. In addition, most non-Japanese firms continue to have difficulty recruiting the most talented engineers and selling products to large Japanese groups.

The experience of Motorola and TI, the two companies with ten–twenty years of experience in Japan, do not suggest to other U.S. competitors that FDI will provide positive benefits. Both companies have stated publicly their dissatisfaction with sales in Japan.[25] When TI entered the Japanese market, it was the undisputed technology and market share leader in the world. Despite twenty-four years of operating in Japan, TI has been unable to appropriate significant benefits from agglomeration: it dropped to number seven in world market share in 1991, with poor profitability. Motorola, number two in the world when it entered the Japanese market, has slipped less (to number five in

25. Motorola's travails are discussed in Yoffie (1987b); TI's public dissatisfaction with its position in Japan was quoted in The Wall Street Journal, March 9, 1991.

1991) but has been even more vocal about its inability to penetrate Japanese customers, despite local manufacturing and local partners committed to expanding Motorola's market access.

7.7 Conclusions

The broad pattern of FDI in semiconductors is generally consistent with many of the broader global patterns we observe in FDI. As one should expect from macrodata, the United States was a large net exporter of capital in the 1960s and 1970s in this industry, while Japan became a large net exporter of long-term capital in the late 1980s and early 1990s.

The motivations for FDI have also been fairly consistent with traditional explanations. In the early period, a search for the lowest labor costs and jumping tariff barriers dominated FDI. During the second wave of acquisitions, efforts to access the advantages of U.S. "dynamism" drove foreign investment. And during the most recent period, politics once again dominated the scene. As one U.S. manager noted, "Europe has been the most successful in blackmailing the world [to force investment in the community]";[26] but Japanese managers would probably suggest privately that the United States has not been far behind.

Despite the very global nature of the semiconductor industry, the experience of Japanese, U.S., and European FDI would not suggest that public policy officials would have any difficulty in answering Robert Reich's questions of "Who is us?" or "Who is them?" The vast majority of fabrication and an even larger percentage of research and development for semiconductors remain at home. Even though more nondomestic, especially Japanese, capacity will come on line over the next decade, the underlying economics will drive successful firms in semiconductors to keep R&D for core products closely coupled with advanced fabrication. Design centers will further spread around the world; more cross-national joint ventures to share the cost and risks of new technologies will evolve. But the heavy weight of history will also keep large employment for assembly in Southeast Asia.

The deeper examination of actual operations by Japanese firms in the United States also suggests that most FDI has been more symbolic than significant. The limited scale of Japanese plants, the slow ramping of production, and the use of second-generation technology in the United States could suggest that Japanese firms look at investments in the United States as options. By putting some capacity in place which can be fully ramped at a later date, Japanese firms retain flexibility to respond to possible protectionism without incurring the full cost penalty of large-scale non-Japanese production. At the same time, they reduce the incentives for protectionism in the United States, because they could ramp local production fairly quickly if duties or quotas were imposed.

26. Interview with a U.S. manager, 1992.

Only when the threat of protectionism is highly credible (as it has been for semiconductors in Europe or for cars in the United States), will firms make large-scale, irreversible capital commitments.

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Comment S. Lael Brainard

Given the ambiguities in the aggregate data, it is refreshing to examine some of the unresolved questions about foreign direct investment (FDI) in a specific industry, and the semiconductor industry provides a particularly rich case. David Yoffie analyzes the evolution of FDI in the semiconductor industry by taking a careful look at industry data combined with anecdotal evidence from extensive interviews. I will restate his argument in somewhat different terms and then suggest issues that it raises.

The implicit argument is that the "natural" pattern of cross-border activity would consist entirely of trade flows. The economics of the semiconductor industry are consistent with each of a few firms establishing neighboring R&D and fabrication facilities (fabs) at a single location, operating at high volume, and exporting globally. This hypothesis is premised on significant plant-level economies of scale and steep learning curves, combined with low transport costs. Due to considerable interfirm, intraregional spillovers and high R&D content, these oligopolistic firms should cluster in one or a few locations with a high density of engineering and scientific skills. In the early years of the industry, the combination of high labor intensity in the final stages of production and an easily separable production structure made it optimal to locate assembly and test facilities in areas with low labor costs. More recently, automation has permitted colocation of testing and assembly with fabrication in areas with higher labor costs. Throughout, internalization of fabrication, assembly, and testing within a unified ownership structure has been warranted by considerable proprietary process technology.

Instead of exclusive reliance on trade, Yoffie argues, there has been extensive FDI and some licensing, which he attributes primarily to trade restrictions in the first case and to a combination of trade and investment restrictions in the second. His analysis presumes a clear ranking of the modes of cross-border market penetration: exporting is most profitable, followed by direct investment, with licensing or joint ventures the least desirable options.

Yoffie distinguishes three phases in the evolution of FDI in the semiconductor industry. The first, from the 1960s to the early 1970s, was characterized by U.S. dominance. Consistent with the natural pattern, industry leaders based in the United States made investments in Asia to tap into low labor costs for assembly and testing. They also made direct investments in the EC in response to tariff barriers. The activities of U.S. firms in Japan were largely confined to licensing, due to a combination of investment and trade restrictions.

The second half of the 1970s was characterized by a number of foreign acquisitions of U.S. semiconductor firms. Yoffie describes the acquisition activity as defensive attempts on the part of several European firms to boost flagging competitiveness.

The third phase stretches from the late 1980s to the present. It has been characterized by investment in greenfield fabs by both Japanese and U.S. firms in the EC and by Japanese firms in the United States. Yoffie describes the EC investments as a response to trade barriers and changes in domestic content regulations, and the U.S. investments as an "option" to hedge against potential trade barriers.

Cross-Border/Cross-Industry and Within-Border/Within Industry Evidence

Given the paucity of firm-level data, an evaluation of the argument comes down to a choice of whether it fits the mostly anecdotal evidence better than plausible alternatives do. The argument would be strengthened considerably by bringing to bear evidence on cross-border investment flows in other industries and on within-border flows in the semiconductor industry.

Thus, for instance, the paper would be more persuasive in discussing Japanese FDI in the United States if it were to incorporate evidence across a range of industries, to distinguish the features that are unique to the semiconductor industry. It is possible that wealth effects associated with the depreciation of the dollar (Froot and Stein 1991) or the Japanese land and stock price bubbles in the latter half of the 1980s explain Japanese investment in the U.S. semiconductor industry no less than in other industries. Indeed, the increase in FDI in semiconductors may have been low in comparison to other industries.

Similarly, Robert Lawrence's finding (chap. 4 in this volume) that there are implicit barriers to inward investment in Japan across a broad cross section of industries might lend support to Yoffie's argument that foreign firms continue to encounter barriers to investment in the Japanese semiconductor industry despite liberalization.

Further, a comparison of cross-border merger and acquisition activity with domestic activity might shed some light on the foreign acquisitions of U.S. semiconductor firms in the late 1970s. Indeed, without such a comparison, it is difficult to dismiss a hypothesis that the acquisitions were driven by internal industry dynamics such as the expansion beyond start-up, or the shift to very large scale integration (VLSI)—rather than declining competitiveness in Europe. Yoffie also notes that all of the European acquisitions from this period subsequently failed. Again, the argument would be strengthened by comparing the foreign failure rate with the domestic failure rate.

Lastly, data on the domestic configurations of semiconductor firms could be used to help determine whether the decentralization of production within firms has been forced by cross-border restrictions or is simply a natural by-product of the industry's evolution. If barriers are the prime driver, there should be more dispersion of production across borders than within borders.

The "Natural" Pattern of Trade

The argument that trade rather than investment would prevail in the absence of barriers slightly begs the question of the natural pattern of trade, which in turn has implications for the pattern of investment. This oversight permeates much recent literature on FDI: although multinational production is widely understood as an alternative to exporting when proximity and internalization advantages exist (Dunning 1988; Caves 1982), rarely is there explicit consideration of the type of trade for which it substitutes.

Depending on the underlying impetus for trade, different predictions for the pattern of investment might emerge. For instance, two distinct models based on differentiated goods might be appropriate for different segments of the industry. A model based on factor proportions (Helpman 1984; Helpman and Krugman 1985) would yield predictions largely consistent with Yoffie's explanation of U.S. investments in the commodity chip segment in Asia in the 1970s. A model emphasizing a trade-off between proximity and concentration advantages for each stage of the business system (Brainard 1992) would predict two-way trade in segments such as microprocessors, with two-way investment occurring only where proximity to customers or suppliers overrides scale considerations.

A third alternative is a model with an intraindustry, intranational learning curve, such as that used by Baldwin and Krugman (1990) in their analysis of the 16K RAM semiconductor segment. In this case, we might expect to see FDI even in the absence of trade barriers to tap into local learning.[1] This might, for instance, explain Yoffie's second wave.

External Economies and the Industry Life Cycle

A third question is applicable to the literature on high-technology industries generally. Yoffie's essay shares with many others in this area a slight fuzziness on the question of what needs to be close to what. Specifying the nature of key externalities more precisely, and analyzing how they change over time, might explain some of the puzzles Yoffie encounters.

There frequently is confusion as to the distinction between innovation resulting from R&D and learning curves—and the extent to which the latter is plant-specific as opposed to firm-specific. Thus, for instance, the prediction that the optimal configuration entails a single fabrication facility is premised on a learning curve that is plant specific within a generation, but it is unclear whether learning is transferred between generations and, if so, whether such transfers are possible across plants. Similarly, the prediction of geographic concentration is premised on agglomeration economies, but it is unclear whether these occur in R&D or learning. If the answer is R&D, is it more important to put R&D facilities close to related R&D labs, fab facilities, or customers? Further, the relative importance of these externalities may shift over time. The recent migration of plants away from Silicon Valley may be a response to changes in external economies over the product life cycle, rather than a contradiction of agglomeration economies. In many industries, geographic

1. The extent to which foreign firms can tap into "home market advantages" via direct investment is an unresolved issue. See Porter (1990).

spillovers between firms are critical in the early stages, which are characterized by high rates of innovation and interfirm learning facilitated by high turnover and spin-off activity. As such industries mature, however, proximity to specialized factors, to supplier industries, or to dense concentrations of customers may increase in importance and eventually dominate,[2] unless externalities between R&D labs continue to be critical or plant investment is long lived. In the semiconductor industry, the latter explanation seems unlikely, since the plant and equipment are obsolete in three to five years.[3]

Indeed, it was surprising to find no reference to vertical linkages in the discussion of location and agglomeration patterns. There is substantial evidence of vertical externalities in the semiconductor industry, both upstream and downstream. The newspapers are full of articles alleging that EC and U.S. semiconductor firms have been handicapped by delayed access to new equipment since Japanese companies gained dominance of the equipment market. There is also extensive downstream integration; it has been prevalent in Japan since the industry's inception and has increased substantially in the United States in recent years.

This is important for two reasons. It is possible that the seeming anomalies in recent fab locations are explained by changing industry economics in which vertical externalities increasingly dominate horizontal externalities. A comparison of the geographical configurations of vertically integrated firms with those of merchant firms might shed light on whether recent location choices were driven by strategic considerations as opposed to barriers. It would be useful to examine whether there is significant colocation of upstream and downstream R&D, and the extent to which downstream activities are themselves dispersed across borders.

Second, in line with Lawrence's analysis (chap. 4 in this volume) of *keiretsu* ties as implicit barriers to investment in Japan, the extensive degree of vertical integration of Japanese semiconductor firms might help to explain the low level of foreign investment into the Japanese semiconductor industry.

The Three Puzzles

Yoffie leaves us with three puzzles; I will comment on each in turn. First, he notes that there is a surprising lack of agglomeration in recent greenfield investments. As suggested above, it is possible that the lack of agglomeration in recent investments is better explained by the shift to VLSI, which has favored vertical integration and large scale over the high turnover and interfirm spillovers associated with agglomeration.

Agglomeration was never a significant factor for the Japanese semiconduc-

2. The importance of these factors may also vary among product segments.

3. The rapid obsolescence is also hard to reconcile with the option interpretation of recent Japanese investment.

tor industry. Many industries are concentrated in the Tokyo-Yokohama corridor and Osaka; this is not unique to the semiconductor industry. Further, there is a sharp difference in the market structures of the Japanese and U.S. semiconductor industries. The Japanese market has never been blessed, or afflicted, by the high rates of entry and exit, employee turnover, and interfirm leakage of technology that have characterized the U.S. market. Instead, the Japanese industry is characterized by stable relationships between semiconductor manufacturers and suppliers, buyers, and financiers, frequently through long-term contracts or ownership, and is dominated by large, diversified industrial conglomerates (MIT 1989).

Second, Yoffie notes that investments in Southeast Asia have been maintained and expanded, even though the automation of assembly and test processes has diminished the importance of access to low-cost labor. However, over the same time period, substantial downstream production (consumer electronics and automobiles) has shifted to this region, and the industrial infrastructure has expanded. It is possible that continued operation in the region is a sensible response to shifts in global production patterns, rather than a sign of inertia.

Third, Yoffie contends that it is surprising to see little FDI into Japan despite liberalization of FDI regulations and implementation of the semiconductor trade agreement (SCTA). This is correct with respect to the liberalization of FDI and corroborates evidence in other industries, as noted above. However, there is no reason to expect increased fabrication investment in response to the SCTA. The SCTA essentially targets the U.S. share of Japanese purchases of semiconductors. Implementation of the agreement would be consistent with rising imports from the United States by Japan, given large-scale economies and low transport costs. And, as Yoffie notes, investment in activities complementary to trade, such as marketing, distribution, and customization, has doubled.

Policy Implications

I conclude by turning briefly to policy implications. If Yoffie is correct, in the absence of barriers to trade, industry economics would imply domination by a few global players concentrated in a few geographical clusters, and there would be no FDI. If we take global share as a proxy for welfare,[4] then the ranking of different policies (in the absence of retaliation) would appear to be (1) joint trade and investment restrictions, (2) no restrictions, and (3) trade restrictions alone. Clearly, this is overstated. Yet, if trade and investment barriers have as deep and lasting an effect on firm configurations as Yoffie's analysis suggests, it is critical for U.S. policymakers to address barriers to both trade and investment in negotiations over semiconductors.

4. This is clearly incorrect, but it reflects the priorities articulated in policy debates.

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Discussion Summary

Robert Feenstra began the discussion by noting that a large fraction of FDI in semiconductors was undertaken by multinationals in order to have manufacturing capacity inside trade walls. It would be interesting to compare the experience of other industries where FDI occurred in response to the erection of trade barriers—for instance, autos. The United States rejected local content rules for autos but erected trade barriers while maintaining free access for FDI. *Feenstra* asked whether these two sets of policies have similar effects.

Someone else asked whether semiconductor FDI into low-wage areas continued because there is still a demand for old-fashioned, labor-intensive products. Why does Malaysia still attract FDI? *David Yoffie* answered that organizational inertia seems to explain this type of FDI. The labor input in these operations is now very small, and equipment, which constitutes 80 percent of the capital, can be moved. Only 20 percent of the capital is immobile plant. The most efficient location for testing and assembly operations in the late 1980s and early 1990s is next to the fabrication facility (fab).

Kenneth Froot asked why geographic agglomerations no longer seem to be important. That is, why do firms put fabs in Ireland and North Carolina instead of Silicon Valley? Saloner and Rotemberg have a model in which firms can hire workers and persuade them to make industry-specific investments in human capital if there are other firms in the area. This model implies that semiconductor firms should continue to locate in Silicon Valley.

Lael Brainard offered another reason for agglomerations: externalities with suppliers. The close ties which Japanese firms have with their suppliers give their fabs a comparative advantage over other fabs. So why are they willing to locate fabs outside Japan?

Yoffie explained that fabs only employ a small number of workers. Therefore, it is inexpensive to find good workers by paying them a premium. In locations outside traditional areas of semiconductor investment, these workers are less likely to quit to go to other fabs. Since labor turnover is very bad for high yields, firms have a strong incentive to locate fabs away from their competitors. *Yoffie* also argued that the benefit of locating near suppliers has declined. Japanese firms are willing to forgo these benefits in order to have production capacity inside actual or potential trade barriers in the United States and Europe.

Robert Lipsey noted that Japanese buyers of semiconductors are all in *keiretsu* and typically buy only from other firms in the *keiretsu.* Thus, demand for the output of merchant firms in Japan is much lower than demand for such output in other countries, and the advantage to foreign firms of investing in Japan in order to sell to the local market is less than the incentive to invest in other countries.

Raymond Vernon asked if foreign firms could, by locating in Japan, establish better contacts with Japanese suppliers and thus obtain the latest technology. He also asked what Texas Instruments (TI) and IBM do? *Yoffie* answered that IBM produces in Burlington for its own use throughout the world. TI has had great difficulty selling to Japanese customers and obtaining the latest technology from Japanese suppliers.

Krishna Palepu asked why governments give subsidies to FDI in semiconductors. *Yoffie* answered that they think there are large externalities but they are wrong. All they get is a little employment for local engineers, but so far no backward or forward linkages. In recent years, suppliers and customers of the semiconductor industry have not followed fabs to new locations.

Martin Feldstein asked whether increased tax revenues will eventually be large enough to pay for the investment incentives. *Froot* noted that persuading the second firm to invest in an area may be cheaper and easier than attracting the first, since the second can steal workers from the first.

Yoffie replied that it is too soon to say whether governments will recoup their tax subsidies but that they probably will not. A modern fab that costs $500 million to build and receives $150 million in investment incentives has perhaps forty workers. Almost all the $500 million is for imported equipment, and almost all the downstream work will continue to be done elsewhere. Governments see that spillovers occurred in Silicon Valley and want to duplicate that experience. But this is no longer happening. Ireland and Italy are only succeeding in spending huge amounts of money bribing firms away from each other.

Richard Marston observed that Compaq's facilities in Silicon Glen in Scotland now supply most of the EC with their computers. This is an example of an assembly operation which took some time to follow the initial fab. Maybe it takes time for downstream spillovers to come.

Feldstein suggested that corruption could also explain why governments give investment incentives to semiconductor firms.

James Hines reported that Puerto Rico gave $140,000 in tax subsidies to manufacturing firms for each $10,000-a-year job that was created. There was no measurable effect on local wages.

Someone else observed that subsidies of lost tax revenues do not cost governments anything, since the multinationals would not have invested in the subsidizing country without the tax benefits. The lost tax revenues come from the country where the investment would otherwise have gone.

Geoffrey Carliner asked if international coordination could prevent multinationals from playing one country off against another. He also asked why the United States does not apply countervailing duties against these types of subsidies.