THE INTERNATIONAL TRANSFER OF SEMICONDUCTOR TECHNOLOGY THROUGH U.S.-BASED FIRMS

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TABLE OF CONTENTS

Table

Table

Table

Figure

Chapter 1

Introduction

This study of the U.S. semiconductor industry seeks to examine its international pattern of exports, licensing, and foreign investments. This industry was selected for study because previous work had shown the United States tended to have a favorable trade balance in industries characterized by high technology processes or products.[1]

The United States semiconductor industry in its short twenty year history has enjoyed a nearly absolute dominance over its foreign competitors. The reasons for the U.S. industry's comparative advantage in world markets has been documented in several studies. John Tilton found that the large demand of the U.S. defense establishment for improved semiconductors was an important factor in generating demand for innovations.[2] He also found that a strong role in the innovating process was played by small, spin-off companies; these firms pressured large semiconductor producers into adopting innovations sooner than they would have otherwise. Tilton stated that over the life of a semiconductor device it would be utilized first in military equipment markets, next in industrial markets, and finally in consumer markets. This pattern was also followed in international markets. An O.E.C.D. study of electronic components arrived at similar conclusions.[3] While these studies described the sources of the technological advantage of U.S. firms, neither explicitly addressed the question of why U.S. firms engaged in exports, licensing, and foreign direct investment.

The study is divided into three parts. The first part, consisting of Chapters 2 and 3, discusses the characteristics of the U.S. semiconductor industry and semiconductor technology. The next part, Chapters 4, 5 and 6.

examines the different transfer channels and the factors which determine a firm's selection between exports, licensing, and foreign production to supply foreign markets. The final section, Chapter 7, seeks to determine the characteristics of the American firms most responsible for the transfer of technology offshore and the impact of foreign direct investment on trade patterns.

The data for this paper were gathered from more than thirty interviews with representatives of semiconductor manufacturers, semiconductor buyers, and knowledgeable industry observers. Two separate questionnaires were utilized to obtain data from over 40 percent of the U.S. companies manufacturing semiconductors world-wide. A majority of the financial and employment statistics were obtained from the annual financial statement, Form 10-K, filed with the Securities and Exchange Commission. Additional information on company activities was obtained from a weekly trade publication, Electronic News.

Chapter 2

Semiconductor Products, Firms, and End-Use Markets

2.a Semiconductor Products

Semiconductors are electronic devices which can amplify, modify, or redirect electrical signals, that is, they are active components. (See Figure 2-1). For many years semiconductors were in direct competition with electronic tubes; but because of the higher performance and lower costs of semiconductors they have replaced tubes in most applications where they are substitutable.

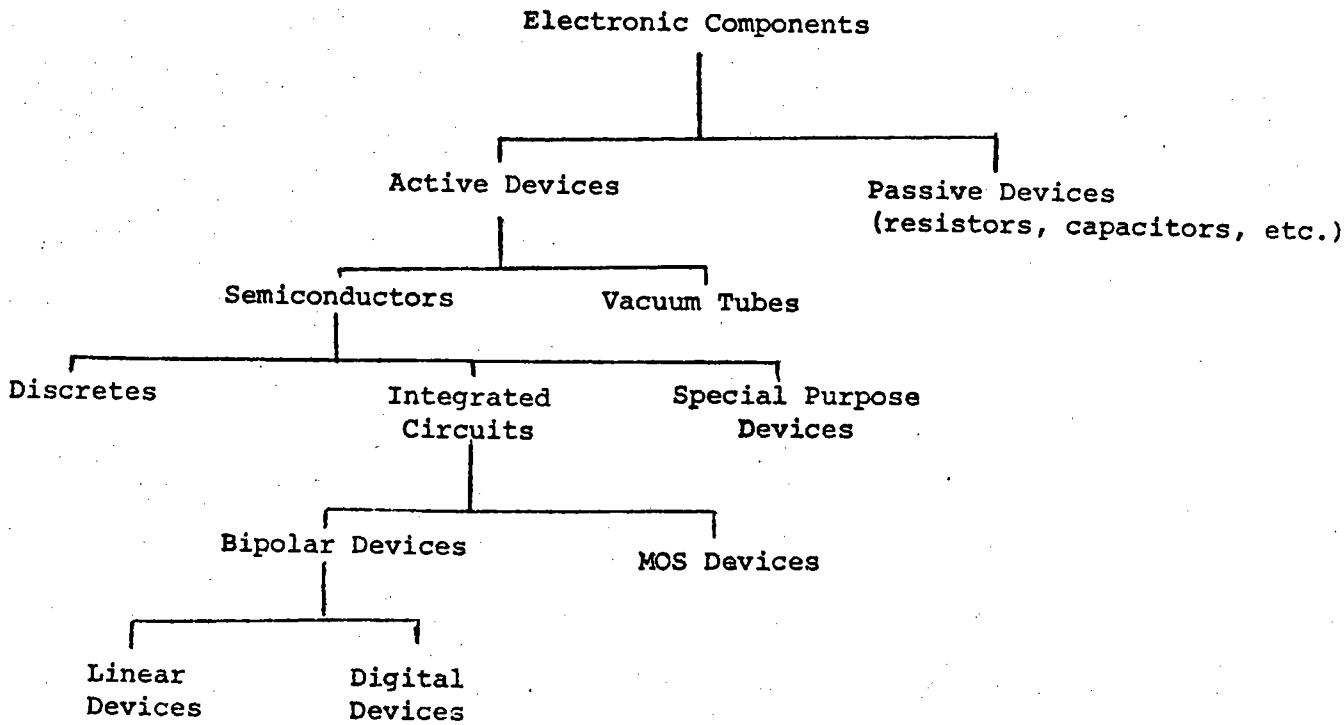
There are three basic categories of semiconductors: first, discrete components, that is, individual devices such as transistors, diodes, rectifiers, etc.; second, integrated circuits which combine the functions of discrete elements into one device; and third, special purpose devices whose characteristics fall outside the other two categories. Integrated circuits (IC) can be divided into either bipolar or metal-oxide-semiconductor (MOS). The final distinction is between linear and digital bipolar devices. Linear integrated circuits yield an output proportional to the input to the device; they are important primarily in industrial and consumer applications. Digital devices are essentially switches registering either on or off; they are especially important in computer applications.

2.b Types of Semiconductor Companies

The Electronic Industries Association (EIA), a national trade association of U.S. electronic manufacturers, defines electronic industries as: "(comprising) industrial organizations engaged in the manufacture, design, and development, and/or substantial assembly of electronic equipment, systems, assemblies, or the components thereof."[1] The semiconductor industry is part of the electronic

Figure 2-1

Semiconductor Products



component manufacturing sector of the industry.

There are three categories of semiconductor manufacturers in the United States: (1) peripheral companies which use semiconductor products, perform research and development on semiconductors, and in some cases manufacture semiconductors for internal consumption ("captive" production); (2) large firms which manufacture semiconductors for sale on the open market; (3) small, independent firms. (The differentiation between the second and third type of firm is arbitrary; small firms, if they are successful, will shift into the second category.) Note that the division between large and small is based on the size of the entire corporation not the semiconductor operation.

The number of firms manufacturing semiconductors in 1972 was about 120.[2] This is approximately the same number that were active in the early sixties. Despite the high attrition of semiconductor manufacturers, there has been a steady number of new entrants to maintain the overall industry size relatively constant. Table 2-1 shows the estimated distribution of firms among captive and non-captive producers and between large and small size in terms of total corporate resources. Approximately one third of the firms in the industry are captive producers. The activities of these firms, except for Western Electric and IBM, will not be discussed in this study.

Despite the large number of participants in the industry, the four largest firms account for 50 percent of total U.S. semiconductor shipments. (See Table 2-2.) The dilution of market share has occurred at the middle level where the largest 20 firms have slipped from 97 percent of total shipments in 1958 to 81 percent of total shipments in 1972. Relating this to

Table 2-1

Estimated Number of Semiconductor Manufacturers by Firm Type and Size, 1972

Type operation		Large[1]	Small	Total
	Captive	24	7	31
	Non-captive	25	43	68
	Unknown		21	21
	Total	49	71	120

[1] Large firms were defined to have either (1) total corporate sales (including semiconductors) in excess of $100 million in 1972 or (2) total semiconductor sales in excess of $20 million in 1972.

Source: U.S. Department of Commerce unpublished data; Securities and Exchange Commission 10-k reports; discussions with industry executives.

Table 2-2

Concentration of Semiconductor Shipments, by Number of Companies

(Percent of Total)

Total Semiconductors, U.S. Shipments, By the	1958	1962	1965	1972
4 largest companies	51	42	50	50
8 largest companies	71	65	77	66
20 largest companies	97	89	90	81
50 largest companies	100	95	96	96
All companies	100	100	100	100

Source: U.S. Department of Commerce, unpublished data.

the number of firms in the industry means that of the approximately eighty non-captive manufacturers of semiconductors, sixty firms have less than 20 percent of the market.

The only peripheral firms of major importance are AT&T (Western Electric) and IBM. AT&T's research arm, Bell Laboratories, has played an important role in the creation and development of semiconductor technology.[3] As long as Bell Laboratories research objectives were compatable with the general needs of the industry it remained the major source of new product and process technology. Bell Labs philosophy "...was to support research in those fields of current basic science that seemed to have the greatest relevance to the mission of the Bell Telephone System."[4] This meant an orientation towards improving communications systems. As semiconductor technology broadened into new areas of applications unrelated to communications, Bell Labs' inputs into the innovative stream lessened in their importance. This was an important change since Bell Labs did a large share of the basic and applied research relating to solid state devices.

While Bell Laboratories declined in its importance to the semiconductor industry, IBM grew. Not only did IBM carry out a substantial research and development program relating to semiconductors, it was also a major user of semiconductors. IBM consumed over one-third of the semiconductors purchased from semiconductor firms by computer companies. Relative to IBM's market share of the computer industry this may seem small; but IBM had a large in-house production capability which supplied 80 percent of the semiconductors it consumed. Another way IBM influenced the development of the semiconductor industry was through its informal ties to Texas Instruments, one of the largest

U.S. manufacturers of semiconductors. As early as 1958 the two firms jointly worked to develop semiconductor devices suitable for computer applications. At one point in the early sixties IBM even developed and transferred to Texas Instruments automated production equipment for the manufacture of transistors. At the time IBM had not yet fully committed itself to developing an in-house production capability.

The large companies which have semiconductor operations can be divided into four types: (1) receiving tube companies (General Electric); (2) successful spin-off firms (National, Signetics); (3) former small diversified companies (Texas Instruments); (4) firms which were already large and which diversified into semiconductors, and large conglomerates (Motorola, General Instruments). **For analysis of these firms, the third and fourth categories will be combined into a single group referred to as conglomerate.**

Receiving tube companies, RCA being the sole exception, have either focussed their semiconductor production on specialized products or have discontinued operations. RCA will be included with the conglomerate category for discussion purposes since its development has been significantly different from other receiving tube companies. Receiving tube companies are not important in the domestic semiconductor industry. They have stayed away from fast changing areas of semiconductor technology.

The remaining types of large firms tend to dominate all phases of established semiconductor technology. The large firms have been the main instruments through which production technology has been transferred abroad. However, the most current and advanced technology is more likely to be exploited by the small, spin-off companies.[5]

Small firms are differentiated by their marketing strategy rather than by the way they entered the semiconductor industry. There are three types of small semiconductor companies: (1) second source companies, these firms duplicate the successful products of other companies; (2) specialty companies, these firms specialize in a very limited area of semiconductor technology; (3) innovating companies, usually formed to exploit innovations not being aggressively pursued by larger companies. Second sourcing a successful product has certain important effects on the transfer of technology within the U.S. semiconductor industry which will be discussed in more detail shortly. Specialty producers are not very important to the overall development of the industry either domestically or internationally. They supply a specialized demand within a broader market for a particular technology.[6] There is a long lag between the initial appearance of an innovative product and the appearance of these companies in the market. This limits their importance in the transfer of technology. The last type of small company, the innovator, is formed to exploit innovations which the larger firms either cannot or will not pursue. Some large firms deliberately let smaller firms have the early lead into new markets. This allows the larger firm to focus its resources on established, profitable markets, while the smaller firms attempt to develop markets for new technology. Once the direction of the market is ascertainable and the type of technology most likely to succeed in it well defined, the larger firms turn their resources to new technology.[7] Texas Instruments and Motorola have used this strategy. The larger firms cannot completely dislodge the small companies from the new markets since they lack the experience with the new process technology. (This point is related to learning economies which will be discussed in the next chapter.)

2.c End-use Markets

U.S. semiconductor industry output is distributed between five end-use markets: (1) consumer (TV, radio, transportation vehicles); (2) computer (mainframes, peripherals, and memory); (3) government (primarily military); (4) industrial (controls, test equipment, office equipment); (5) other (export, distributor). The export market will be discussed in Chapter 6. In terms of influence on the growth and direction of semiconductor technology, historically the military market has been the most important; but the computer and consumer markets have superseded the military market.

The military was the largest end-use consumer of semiconductors until the middle sixties. (See Table 2-3). It was willing to pay premium prices to obtain higher performance and reliability. For example, during the first four years integrated circuits were in production (1961 to 1965), the military purchased nearly 90 percent of all circuits produced. Only after the average price per circuit declined 80 percent did other users begin to purchase integrated circuits in substantial quantities.[8] In this same period the number of companies producing integrated circuits in the United States increased from two to over thirty. The military's willingness to utilize the most advanced devices in its equipment encouraged the formation of new companies interested in rapidly developing n avenues of semiconductor technology.[9] This was an important factor in the early development of the industry. It tended somewhat to confine the U.S. industry to producing high priced devices for the military equipment market.

The computer market overtook the military as the major market in the mid-sixties. Computer firms, like the military, demanded highly reliable devices; but, unlike the military, they were unwilling to pay premium prices to obtain

Table 2-3

Distribution of U.S. Semiconductor Sales[1] by End Market

End Market	1960[2]	1968[2]	1972[3]
Computer	30%	35%	28%
Consumer	5%	10%	22%
Military	50%	35%	24%
Industrial	15%	20%	26%
Total	100%	100%	100%
Total Value (Millions of $)	560	1,211	1,378

[1] Sales in dollars

[2] Texas Instruments estimate

[3] J. P. Ferguson Associates estimate

higher performance. Price was the key variable to widespread penetration of semiconductors into computer applications. Only after price declined significantly did computer companies begin to redesign their equipment around the new devices.

The consumer market was the last major market to develop in the United States. It was and has remained relatively passive in its relationship with producers of semiconductor devices. Less concerned about performance and reliability, consumer end-users primarily considered price the main barrier to increasing their use of semiconductor technology. Semiconductor firms aggressively sought to "pull" consumer end-user technology along. This intensified the marketing orientation that developed in the industry as it tried to interest non-military markets in semiconductor technology.

2.d European and Japanese Semiconductor Industries

While the purpose of this study is to examine the patterns of technology transfer by the U.S. semiconductor industry, it will be useful to briefly discuss the major foreign semiconductor industries of Europe and Japan. The discussion will rely primarily on the studies by Tilton and Golding.

Both the European and the Japanese semiconductor industries lacked the early support from military buyers which American firms enjoyed. Their industries therefore became oriented towards serving the entertainment and industrial end-markets. Since these markets did not require the higher performance devices the U.S. industry produced for the military market, both foreign industries lagged in the development of advanced semiconductor technology. American industry members interviewed for this study expressed the belief that foreign firms lacked an understanding of the importance of the product life cycle on semiconductor technology. (The product life cycle is discussed in Section 3.e.) They felt that in the past Europeans had been particularly slow in changing over to newer products.

While the behavior of the foreign firms cannot be easily explained, Tilton notes several important factors which accounted in part for their unwillingness to react as quickly to changing market conditions as American firms. The lack of venture capital to encourage formation of new firms, limited mobility of engineering talent, and patent restrictions all tended to inhibit new competitors from entering foreign industries from within. Tilton notes that major new entrants into the European semiconductor industry have been the subsidiaries of American firms. He further states that the barriers for entry of new European firms are increasing while entry barriers for foreign subsidiaries are decreasing.[10/11] In contrast to the U.S. industry, the receiving tube firms in Europe played a major role in the innovative process. But without the spin-off firms to exploit these innovations, the European industry did not pursue their applications.

The Japanese semiconductor industry has been completely dominated by large firms. The largest four firms supplied 72 percent of the Japanese market in 1968;[12] the largest 9 firms accounted for 90 percent. The high degree of industry concentration was due to government policies which limited entry to the industry. The Japanese government sought to overcome the American dominance of the world semiconductor market. To achieve this objective they felt that their limited research and development resources had to be concentrated in a small number of companies. By 1972 the number of firms in the Japanese industry totaled only about 20. (Of the 20 firms, about one-third were joint ventures with foreign companies, primarily American.) To protect the domestic industry from foreign competition, foreign wholly-owned subsidiaries were not allowed and import restrictions were applied to advanced devices. These barriers were dropped by 1974. The strong influence of the Japanese government on the industry's development prevents any meaningful examination of market related events in Japan. The patterns of U.S. offshore investment described in Chapter 5 reflect the restrictiveness of the Japanese government.

Chapter 3

Semiconductor Technology

3.a Process Technology

To understand the outward flow of technology in the U.S. semiconductor industry, it will first be necessary to describe the process technology in detail. The process technology consists of four elements: (1) device design; (2) fabrication; (3) assembly; (4) final testing and sort. There are several materials used to make semiconductors, but the most prevalent by far is silicon. The description of the manufacturing technology which follows will be the silicon planar process. It was first used by Fairchild nearly fifteen years ago and it is still the dominant process in use today.

The manufacturing sequence starts with the drawing of the circuit at several hundred times its final size. The artwork is reduced and working copies are made. The copies of the design are used to make photomasks. The photomasks or "masks" are used in the next process stage to transfer the circuit design to the silicon material. (Semiconductors can be manufactured by companies without in-house mask-making capability. External suppliers can take the company's circuit design and produce the photomasks.)

The fabrication of the semiconductor devices from the silicon material is a highly sophisticated sequence of operations. Fabrication technology is the key element of the process. Only by mastering fabrication can a company be an independent supplier of semiconductor devices.

The silicon material used to make semiconductors is in the form of thin, highly polished crystal wafers; the wafers are generally two and a quarter or three inches in diameter. The fabrication sequence starts with the alignment of the photomask to a wafer. The silicon wafer, which has been coated with a light-sensitive emulsion, is exposed to a high intensity light which transfers the circuit design to the wafer. The pattern on the wafer defines regions into which selective impurities will be introduced via diffusion. Diffusion takes place in high temperature furnaces; the impurities in the silicon will form various electronic components. The masking-diffusion sequence can be repeated several times depending on the complexity of the circuit being fabricated. A layer of aluminum is added after the final diffusion and etched to form selective electrical interconnects on the wafer. The last step is oxidation of the wafer. The wafer now contains anywhere from a few hundred to several thousand individual circuits.

Throughout the design and fabrication sequence the photomasks and wafers are continually being visually inspected. The visual inspections are to prevent further processing on wafers which are entirely lost due to improper masking or diffusion. After the final fabrication step, the individual devices formed on the wafer are electrically tested. The electrical test of the wafer is a high speed, highly automated process. It is preferable to detect as many of the bad devices at this stage since the cost of further processing of bad devices is very high. Once the wafer electrical test is completed, the wafer is scribed by a diamond stylus and split into individual devices or chips. The number of chips per wafer can range from several hundred to as many as several thousand; the size of the chips determines the number per wafer.

Processing continues only on the devices which passed inspection.

The chips now enter a series of assembly operations. There are several types of assembly methods. The most common form of manual assembly will be described. First, the assembler picks up the chip, aligns it on a base and bonds the base and chip together. Another assembler attaches very fine connecting or lead wires to the chip; then the chip is sealed in a protective package.

The last series of process steps are final test and sort. The completed device is subjected to a final electrical test to determine its electrical characteristics. Chips which pass the test are graded according to their specifications. Like the earlier electrical testing of wafers, this is a capital intensive operation. Devices of extremely high complexity require testing supported by a computer.

An interesting aspect of the manufacturing technology is the way it is segmented. The design phase can be accomplished at a completely separate facility from the remainder of the manufacturing sequence. It is very difficult to obtain accurate information on the location of design facilities and they will not be discussed at length in subsequent chapters detailing foreign operations of U.S. companies. Of the remaining elements of the manufacturing operation, wafer fabrication is usually done at one facility, assembly and test at another. The fabrication is carried up to the point just prior to the splitting of the wafer. The wafers are shipped to an assembly plant which can be located anywhere in the world since transportation costs are relatively minor compared to the value of the wafers. (See Section 5.a.4). Final electrical test can be located either at the assembly plant or at a central location within the United States. Whether final testing is done at the assembly plant or elsewhere depends on the final destination of the devices and the complexity of the final testing. If devices are to be sold outside the U.S., final testing would probably be done at a foreign assembly facility. The major exception would be for complex devices requiring heavy investments in testing and computer support systems. Most final testing of complex devices is done in the United States due to the economies of scale.

The separation of the wafer fabrication processing from the assembly processing is due to differences in factor requirements and economies of scale. Wafer fabrication requires a large capital investment as well as a large fixed overhead of engineering and ancillary personnel and equipment. A major component of the capital is in clean rooms and air conditioning systems. The average investment in a wafer fabrication facility (plant and equipment) would be $500 per square foot.[1] Investment in an assembly plant would be only about $200 per square foot.[2] The assembly plant does not require the special air conditioning or clean environmental conditions that the fabrication plant does. Assembly is typically a labor intensive operation with only a fraction of the fixed overhead found in the fabrication plant. An additional difference, learning economies, also allows fabrication and assembly operations to be separated. Subsequent sections will describe factor requirements, economies of scale, and learning economies in greater detail.

A final distinction concerning semiconductor technology must be made between product related and process related technology. The design and final test phases can be categorized as product related technology. That is, these two phases deal with individual device design, photomasks, and final operating specifications. Wafer diffusion technology and assembly technology are process related. Techniques used in these phases of production are applicable to a broad range of semiconductor devices. For different devices, certain techniques may be repeated several times to achieve the necessary result, but the techniques generally are not related to a specific product.

3.b Process Yields

The semiconductor manufacturing process is considered one of "the most complicated high-volume processes ever developed by man."[3] The complexity of the process results in something very unusual in mass-produced products. Only a fraction of the chips (originally wafers) which start the production sequence complete it as usable devices. The fraction which survives can vary from 80 percent for simple devices with mature process techniques down to 5 percent for complex devices with new process steps. The terms used to denote the percentage of the original chips which are marketable after final electrical test is "yield".

At each step in the process sequence a certain percentage of the chips will be lost. Prior to wafer electrical test, losses are to entire wafers. Wafers which are marginally good will be processed through to electrical test because of the high marginal revenue obtained from good devices. Wafer electrical test is the critical selection point because the costs of assembly are high; it is very important for firms to let only good devices continue into the assembly phase.

Yields in assembly average about 90 percent because stringent tests are applied before the splitting of the wafer. The final electrical test is also a critical juncture in determining the success of the process sequence. Yields at this test point reflect the efforts of the entire manufacturing sequence.

It will be useful at this point to develop an equation for the total manufacturing costs per chip. Losses to chips are assumed to be taken at four points in the manufacturing sequence. Y_1 is the yield of wafer fabrication and C_1 the cost. Y_2 is the yield at wafer electrical test and C_2 the cost of performing the test. Y_3 is the yield after bonding the chip to a base and attaching wires; C_3 is the corresponding cost. Y_4 is the yield at final electrical test; C_4 is the cost of packaging and testing the device. Costs include material (where appropriate), direct labor and manufacturing overhead. C_1 and C_2 are costs per wafer; C_3 and C_4 are costs per chip. N is the initial number of chips per wafer; this is a function of the size of the wafer and the size of the chip. The total manufacturing cost per chip is:

$$(3.1)\quad \text{Total Cost per Chip} = \frac{C_1}{Y_1 Y_2 Y_3 Y_4 N} + \frac{C_2}{Y_2 Y_3 Y_4 N} + \frac{C_3}{Y_3 Y_4} + \frac{C_4}{Y_4}$$

Table 3-1 shows the application of this formula to a relatively mature product while Table 3-2 shows the results for a newer, more complex product.

3.c Learning Economies

As implied earlier, yields are not static. As the production process matures, yields improve. Semiconductor firms in the past have experienced dramatic improvements in yields as production volume accumulates. Average costs are believed to decline between 20 and 30 percent each time cumulative production doubles.[4]

Table 3-1

Manufacturing Yields and Costs for a Mature Product

(T^2L Integrated Circuit)

Manufacturing Step		Yield	Cumulative Yield	Cumulative Cost[1] per Chip
1a. Wafer Fabrication (costs computed before losses)		100%	100%	$0.007
1b. Wafer Fabrication (yielded)	Y_1	80%	80%	$0.01
2. Wafer Electrical Test	Y_2	40%	32%	$0.025
3. Chip Bonding & Wiring	Y_3	90%	29%	$0.029
4. Final Electrical Test	Y_4	90%	26%	$0.033

[1] Assume 2385 chips per wafer; cumulative costs include materials, direct labor and overhead for each successive step; assembly performed in Singapore.

Source: J.P. Ferguson, President, J.P. Ferguson Associates.

Table 3-2

Manufacturing Yields and Costs For An Immature Product

(1103 MOS Integrated Circuit)

Manufacturing Step		Yield	Cumulative Yield	Cumulative Cost[1] per Chip
1a. Wafer Fabrication (costs computed before losses)		100%	100%	$0.107
1b. Wafer Fabrication (yielded)	Y_1	70%	70%	$0.153
2. Wafer Electrical Test	Y_2	20%	14%	$0.926
3. Chip Bonding and Wiring	Y_3	85%	11.9%	$1.09
4. Final Electrical Test	Y_4	75%	8.9%	$1.45

[1] Assume 140 chips per wafer; cumulative costs include materials, direct labor and overhead for each successive step, assembly performed in Singapore.

Source: J.P. Ferguson, President, J.P. Ferguson Associates.

Though learning economies take place throughout the manufacturing sequence, firms concentrate their efforts for improvement in the wafer fabrication stage. The reason for this is obvious. Yields are normally very high in the assembly stage; in the examples cited in Tables 3-1 and 3-2 a 5 percent improvement in assembly yield would also decrease costs 5.5 percent. A 5 percent improvement at the wafer fabrication stage (increasing wafer electrical test yields) results in over a 20 percent decrease in cumulative costs per chip.

The necessity for improvement in yields at the fabrication stage of production is one reason why firms carry on this operation in a minimum number of plants. They are seeking to create a situation where learning economies are the greatest. If learning economies are associated with accumulated volume, maximizing learning economies means concentrating fabrication in a limited number of facilities. Assembly operations are also subject to learning economies but not nearly so important or large. Assembly operations can go on at multiple locations with very little impact on overall costs resulting from learning economies being adversely affected. Once the wafer is split at an assembly plant, the assembly operation becomes very labor intensive. Minor process changes can be made and some increases in assembler productivity, but neither of these improvements results from the concentration of assembly activity.

3.d Economies of Scale

Earlier studies have minimized the importance of economies of scale in the semiconductor industry.[5] This may have been true during the early development of the industry, but for several reasons this has changed. The changes have taken place both at the plant level and at the firm level. First, the stability of the silicon planar process technology has allowed firms increasingly to automate the wafer fabrication process. Second, the complexity of newer devices has forced firms to use highly sophisticated testing equipment. One estimate is that 20 percent of the present industry capital expenditures are going for new test equipment; previously, the rate was estimated to average about 2 percent.[6] A third reason, related to firm size, is that because of rapid product turnover, firms have had to fund substantial research and engineering staffs to maintain their competitive position.[7] In many cases, these research staffs are merely trying to duplicate a competitor's product rather than develop a new device. Table 3-3 shows the estimated distribution of manufacturing costs between materials, direct labor, and manufacturing overhead (indirect labor, ancillary services expenditures). Fixed manufacturing overhead accounts for an estimated 50 percent of total costs and one third of the selling price on the average. Corporate overhead (administration, marketing, research and development expenditures) accounts for an additional 25 percent of the total selling price.

As noted earlier, the wafer fabrication process is a completely different type of operation from assembly. All of the build-up of fixed charges, with the exception of test facilities, has occurred in the wafer fabrication stage of manufacturing. This has increased the differences in the cost structure of the two main process stages.

Table 3-3

Distribution of Costs

	Manufacturing Cost	Sales Price
Direct Manufacturing Overhead	50%	33%
Labor	20%	18%
Material	30%	14%
Corporate Overhead	--	25%
Profit	--	10%
Total	100%	100%

Source: Interviews with industry members.

Table 3-4

Decline in Price for Fairchild Planar Transistor

Date	Price per Device
February, 1958	$150.00
August, 1958	75.00
January, 1959[1]	45.00
July, 1959	28.50
February, 1960	22.70

[1]Volume ten times greater than in August, 1958.

Source: Electronic News, July 15, 1960, p. 4.

3.e Pricing Strategies

Significant learning economies and the relatively large fixed overhead lead semiconductor companies to strive to create market volume. As each new product technology begins its growth phase, firms rapidly cut prices to secure a share of the growing market. Table 3-4 shows the price reductions Fairchild made on its planar transistor over a two-year period; the total decline was 85 percent. This type of rapid price reduction in a growing market is called "penetration pricing."[8] The purpose of such a strategy is to emerge from the growth era with a dominant market share.[9] Once the market shares stabilize, the rate of price decline slows. Since dominant market position assures greatest accumulated volume, the dominant firm's costs continue to decline. The result is ultimately high returns in late phases of the product life cycle. A corollary to this strategy is that a declining price broadens the potential customers for a device. Thus firms can find themselves in a growing market, with declining market shares, yet gaining in their absolute sales volume.

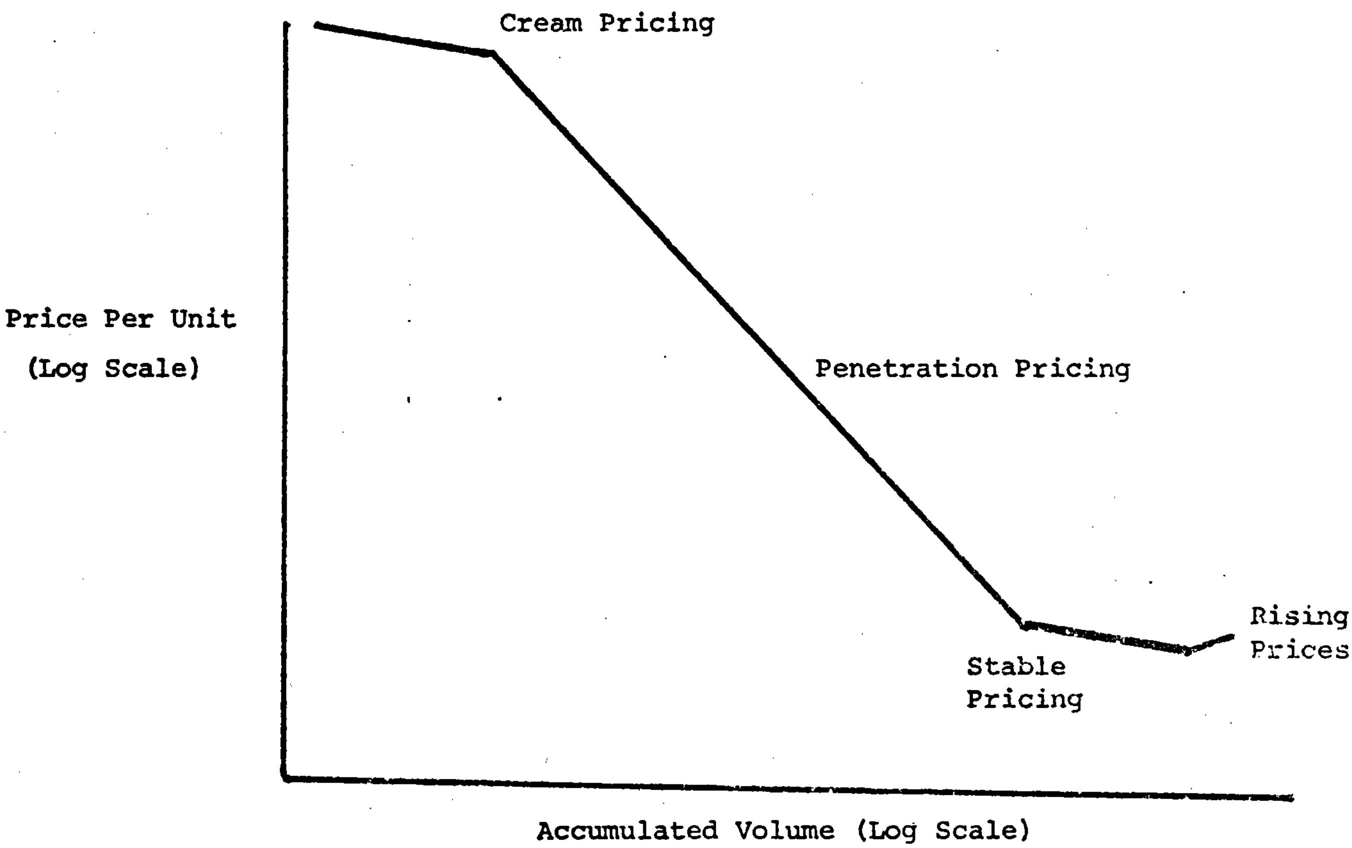
An alternative pricing strategy is called "cream pricing."[10] Here a firm attempts to market to customers who are willing to pay a premium for high-performance devices. Rather than waiting to make a return in the later stages of the product's life cycle, this strategy attempts to gain a rapid return in the early phases of the life cycle. Robert N. Noyce, while with Fairchild, stated, "the way to make money in semiconductors is to sell a better product to somebody who can't wait for a price cut."[11] The only customers willing to pay premium prices are the military and in some instances computer manufacturers. Once the industry catches the innovator, the pricing strategy degenerates into the rapidly declining patterns associated with penetration pricing.

Figure 3-1 shows the general tendency for prices over the product life cycle. Initially there is a period of slow declines as firms recoup their research and development costs by marketing to customers willing to pay premium prices for innovative devices. (The initial phase does not always appear as firms may immediately commence large price reductions to broaden the potential market.) The next phase is one of rapidly falling prices. During this stage firms may cut prices below costs in an attempt to improve their market position. The hope is that they can hang on long enough to survive in the market until accumulated volume brings costs below market prices. Prices begin to stabilize when the product has matured and market shares are firmly established.

The final phase of rising prices occurs when the product reaches the latter stages of the declining phase of the product cycle and begins to be phased-out. As fewer firms manufacture the product and demand falls off, the remaining suppliers can increase their prices.[12] There are several reasons why this occurs. First of all, costs increase since overhead costs have to be distributed over a declining volume of output. Second, the remaining users usually require very specific device characteristics; if this weren't true they would have switched into newer devices. Third, devices completed at final electrical test are sorted according to their electrical characteristics. With a large number of buyers with varying requirements, all of the devices passing final electrical test can be sold; but when the market is narrowed down to those with particular requirements, only a portion of the final

Figure 3-1

Price Per Unit Over the Product Life Cycle



Introduction ⟶ Growth ⟶ Maturity ⟶ Decline ⟶ Phase-Out

(Stages of the Product Life Cycle)[1]

Source: Discussion with industry members.

[1] Not to scale.

output can be sold. This adds to the increase in cost since it is effectively lowering the yield of the production process. Finally, since the remaining buyers for the obsolete devices are locked-in to their use, their demand is relatively price inelastic. The smaller number of suppliers raise prices in the declining market.

The practice of rapidly reducing prices has had two important indirect effects on the industry. It has forced some firms, particularly the receiving tube companies like Westinghouse and General Electric, to seek refuge from the competitive turbulance by focusing their marketing efforts on narrower, more stable technologies. Usually this has meant concentrating on discrete devices. An executive of one large company was quoted as saying, "One of the nice things about being in the discrete business is that you know that the competition isn't going to be spending any more money to gain further penetration in the market. We see that as a stabilizing influence on the price."[13]

The instability of prices has also reinforced the tendency to introduce new product technology rapidly. It takes approximately 2 to 3 years for new products to reach the declining stage of the product life cycle.[14] The duration of the declining stage varies widely. Firms which fail to obtain adequate market share with one product can move on to the newer products to try to build up a market there. RCA has had success with this "leapfrogging the technology."[15] Conversely, firms which do get established in a product seek ways to extend the product's life cycle; the longer the life cycle the greater the returns to the dominant firms. The greatest returns come during the late portion of the mature stage of the product life cycle. Prices are stable and costs are at their lowest.

3.f Second Sourcing

The intense price competition described previously is in part due to the speed with which competitors can copy an innovative device. Discussions with industry members indicate that the general belief is that a new product can be duplicated by most manufacturers within six months of initial introduction. (This assumes that the imitating firms already have the necessary process technology.) Closely related to imitation but not identical to it is "second sourcing." Second sourcing is defined as the manufacture by another firm of a device which has identical specifications and which is directly interchangeable with a device first produced by the pioneering firm. Second sourcing differs from imitation in that imitators adopt the innovation but do not duplicate the innovator's product exactly; second sourcing also originally involved the cooperation of the pioneer firm. The practice of second sourcing has affected the transfer of semiconductor technology both within the U.S. industry and between U.S. and foreign companies. The latter type of transfer will be discussed in Chapter 4.

Second sourcing was originally a formal arrangement between semiconductor firms supplying devices meeting military standards and prime military contractors purchasing the devices. The contractors required an alternative source besides the semiconductor company selected to fulfill the bulk of the contract. Firms designated as second source suppliers would receive the specifications of the devices the major supplier was delivering to the prime contractor. Second source agreements became more generally used when small semiconductor companies began to request large companies to become their second source suppliers to the non-military market. A less formal form which is also common is the unsolicited second sourcing of one company's successful product by its competitors.

The product is duplicated without any assistance from the original producer. Many semiconductor products are not difficult to copy if the process technology is known. The remainder of this section will deal with the effects of the last two types of second sourcing on the transfer of technology.

Both large and small companies second source; but there is an asymmetry about the reasons and the results for each type of firm. Small companies with new products actively seek second sources among larger manufacturers. Normally they cannot gain broad acceptance for their product. There is a price-market circle which needs to be broken. That is, to gain broad market acceptance requires price reductions; price reductions require broad market acceptance. Small firms usually cannot cut prices and hope to survive long enough for the market to develop for their product. There is also another factor besides price which prevents small firms from penetrating the market with a new product. Buyers of semiconductor devices have traditionally been reluctant to rely on a single source of supply, particularly an untried new firm.

The small firm is forced to seek out a larger firm with complementary technical skills and the marketing clout to create a new market. The small firm will lose market share but the absolute size of the market will increase. An example of a formal second source agreement between a small and large company was a 1973 agreement between Advanced Memory Systems (AMS) and Texas Instruments (TI). TI agreed to "officially announce as a source for an integrated circuit equivalent to the AMS 7001 and to use its best efforts to actively market that device as a standard product."[16] AMS made a similar second source arrangement with Motorola whereby Motorola received a set of photomasks and supporting documentation.[17] There were no restrictions on where Motorola could market the device.

Besides losing market share, there is another drawback to second sourcing agreements from the small firm's standpoint. As mentioned above in the case of the AMS-Motorola agreement, second sourcing agreements usually do not restrict where the large company can market the device it copies. Since the larger firms usually have international sales and manufacturing facilities, opportunities for the small firm to develop a market abroad are reduced. The larger firm, although lagging behind the small company in initially producing the device, can more effectively market the device in foreign markets.

Large companies normally do not need to solicit second sources. Since they are already cross-licensed to use each others' technology, any large company can second source another one with no legal repercussions. Like the smaller semiconductor companies, the larger firms are interested in having their products second sourced. The more firms that second source a product, the greater the degree of market standardization around it. Once a product is second sourced, the original supplier can expect increasing price competition as the penetration pricing phase starts. But since the original supplier also has the greatest production experience, presumably his lower production costs enable him to benefit from the growing demand.

The inability of small firms, in most cases, to break the price-market circle independently of large company support allowed the larger firms to duplicate almost any innovation marketed by the small firms. The ease of access to the innovative technology of the smaller firms diminished the requirement for large firms to maintain technical superiority. The more radical the technology marketed by a small firm, the less likely it was that a larger firm would convert part of its production capacity to imitate the new product.

The risks were too great that the market would not develop. Larger firms were willing to let the smaller firms use their resources to develop new products and try to create a market for them, even though this would give the small firms a head-start if the market developed.

The ability of large firms to rely on second source agreements to keep them abreast of new product innovations has been curtailed in certain areas of semiconductor technology. Complex metal-oxide-semiconductor (MOS) integrated circuits have been especially immune to the traditional methods of duplication. This has added a degree of risk to the "wait-and-see" strategy followed by the larger firms. This was demonstrated by the ability of Intel, a spin-off of Fairchild, to develop the market for an innovative MOS technology without the assistance of larger firms. Intel did arrange for a company to second source its product to satisfy the demands of its customers for two sources. But it selected a technically weak company to act as its second source to minimize potential competition. Intel could pursue this different strategy since its innovation was primarily in process know-how, something not easily copied.

3.g Semiconductor Innovations and Innovators

The American semiconductor industry's favorable international competitive position has been partially attributed to its high rate of technological development. This section will briefly discuss the historical pattern of innovative activity in the industry and how it has changed.

Semiconductor technology has evolved through three distinct phases. These phases roughly correspond to the transition in importance of the different end-users of semiconductor devices discussed in Section 2.c. The first phase was the creation of the basic semiconductor technology; this started with the invention of the transistor and lasted until the integrated circuit was commercially marketed in 1962. The second phase was the development of production techniques which could lower costs and produce highly reliable devices. This lasted until about 1967. The final phase of industry growth was the marketing era. Semiconductor firms in this phase sought to penetrate new markets.[18] It was during this last stage of industry development that over 80 percent of the foreign direct investment of American semiconductor firms occurred.

The effects of the changeover from the generation of new know-how to the application of already existing know-how can be seen in Tables 3-5 and 3-6. Between 1960 and 1965 there were fifteen major semiconductor innovations. In the subsequent nine years there were only seven. Expenditures for research and development (R&D) also reflects the increased emphasis on marketing existing technology. In 1959, for example, total R&D expenditures were $70 million or about 19 percent of industry sales.[19] But by 1972, total R&D expenditures represented only about 10 percent of industry sales or $136 million. (These figures exclude Bell Labs and IBM.) Basic research today is being done in any substantial amount only by the peripheral firms. (See Table 3-7.)

A final word is necessary to explain the list of innovations in Table 3-6. Identifying semiconductor innovations is not an easy task. Since the innovation of the integrated circuit, a large number of follow-up innovations related to this initial break-through have appeared. Tables 3-5 and 3-6 follow Tilton and Golding in the practice of identifying the devices or processes which represent "major" improvements in either cost or performance. The problem of developing any list of innovations in the industry arises from the fact

Table 3-5

Major Semiconductor Innovations 1960-1965

Innovation	Firm	Date
1. Planar Transistor[1]	Fairchild	1960
2. Epitaxial Transistor[1]	Western Electric	1960
3. Planar Process[1]	Fairchild	1960
4. Epitaxial Process[1]	Western Electric	1960
5. Integrated Circuit[1]	Texas Instruments	1961
6. MOS Transistor[1]	Fairchild	1962
7. DTL Integrated Circuit[2]	Signetics	1962
8. ECL Integrated Circuit[2]		1962
9. Gunn Diode[1]	IBM	1963
10. Plastic Encapsulation[1]	General Electric	1963
11. Beam Lead[1]	Western Electric	1964
12. TTL Integrated Circuit[2]	Pacific (TRW)	1964
13. Light-emitting Diode[3]	Texas Instruments	1964
14. Dieletric Isolation[3]	Motorola	1965
15. MOS Transistor[2]	General Microelectronics General Instruments	1965

[1] John E. Tilton, International Diffusion of Technology: The Case of Semiconductors (Washington, D.C.: The Brookings Institution, 1971), pp. 16-17.

[2] Anthony M. Golding, "The Semiconductor Industry in Britain and the United States: A Case Study in Innovation, Growth, and the Diffusion of Technology" (Ph.D. dissertation, University of Sussex, 1971), p. 81.

[3] Discussions with scientists, engineers, executives in the semidonductor industry.

Table 3-6

Major Semiconductor Innovations 1966 to the Present

1.	MOSFET (MOS-field effect transistor)	Western Electric Philips	1968
2.	Collector diffusion isolation	Western Electric	1969
3.	Shottky-clamped logic circuit (TTL)	Texas Instruments	1969
4.	Charge-coupled devices	Fairchild	1969
5.	Complementary MOS	RCA	1969
6.	Silicon-on-sapphire	RCA	1970
7.	Ion Implantation	Unknown	1970

Source: Discussions with scientists, engineers, executives in the semiconductor industry.

Table 3-7

Estimated Expenditures for Basic Semiconductor R&D by U.S. Semiconductor Industry-1972
($ Million)

Bell Laboratories (Western Electric)	$15
IBM	13
RCA	4
Texas Instruments	2
Other (General Electric, Fairchild, etc.)	2
Total	$36

Source: Interviews with industry members.

that semiconductor firms which are developing new integrated circuits are continuously achieving incremental improvements in cost and performance characteristics. Listing all innovations would be unrealistic. The vast majority represent only minor changes. The criteria used to determine which innovations were significant were first how pervasive the innovations were in the industry and second did the innovation represent a radical advance over previously existing technology. Using this relatively narrow criteria results in the addition of nine innovations to Tilton's and Golding's lists.

A different definition of innovation was used to identify companies that could be regarded as innovators within the industry. Any firm which was attempting to improve the characteristics of its products or processes over existing levels was defined as an innovator. Using this broader definition meant that a firm without an innovation to its credit in Tables 3-5 or 3-6 may still have been classified as an innovator. Spin-off companies classified as innovators have usually been exploiting the inventions of other firms. Very few of these spin-off companies developed the original invention which formed the basis for the company.

Chapter 4

Licensing

This chapter begins the portion of the study dealing with the international development of the U.S. semiconductor industry. Licensing will be discussed before exports and foreign production because it has not been a major means of transferring semiconductor technology to foreign firms unaffiliated with U.S. companies.

U.S. semiconductor companies grant two basic types of licenses. The first is a patent license which gives the licensee the right to use specific patents of the licensor. The benefits to the licensor are the legal recognition of his patent claim, in some instances royalty income, and frequently, the reciprocal privilege to use the semiconductor-related patents of the licensee (under a cross-licensing agreement). The second type of license overlaps the first since it also grants legal permission to the licensee to use patents of the licensor, but has the additional benefit for the licensee that technical assistance is included in the agreement. This assistance can be in the form of visits by engineers, transfer of photomasks, or the transfer of process specifications. This type of license can be in the form of a know-how license or a second source agreement. The benefit to the licensor of these licenses or agreements are the additional return on his investment and standardization around his technology.

4.a Patent Licensing

Of the two types of licenses, patent licenses are the more prevalent according to the common view expressed in interviews with major firms which license.[1] Patent licenses normally do not convey any technical know-how to the licensee; the major exception, which will be discussed shortly, is Western Electric patent licenses. In most instances a firm requesting a patent license already is using the technology covered by the license. It is only seeking to avoid litigation over patent infringement by obtaining a license.

Patent royalties paid by foreign firms have steadily increased. While no figures are available for European licensee payments, annual Japanese patent royalty payments between 1964 and 1970 for semiconductor and integrated circuit licenses went from $2.6 million to over $25 million. (See Table 4-1).

In a sample of 42 U.S. semiconductor companies (excluding Western Electric), about a third of the total industry, the large companies were the most active patent licensors (See Table 4-2). The 7 large firms which frequently issued patent licenses each had over 50 U.S. patents relating to semiconductor technology awarded to them between 1952 and 1968.[2]

Texas Instruments, Fairchild, and Western Electric dominate the patent license market because they have strong patent positions. These firms actively seek to capitalize on their technical leadership by obtaining royalties for use of their technology and a cross-license for access to the licensee's patent technology. The royalty rates charged by these firms depends on several factors: (1) the number of patents covered by the license agreement; (2) the technological capability of the licensee (companies with strong research programs may receive a royalty-free license since the licensor under a cross-license agreement gains the use of the licensees patented technology); (3) the licensor's licensing competition. With respect to competitive influences, small firms, for example, may

Table 4-1

Japanese Patent Royalties for Semiconductors and Integrated Circuits Paid to U.S. Licensors 1964-1970

($ Thousand)

	Semiconductors	Integrated Circuits
1964	2,583	---
1965	3,456	---
1966	4,255	---
1967	5,356	---
1968	5,936	---
1969	8.578	5,278
1970	17,011	8.112
Total	47,175	13,390

Sources: The Ministry of International Trade and Industry, Japan and the Electronic Industries Association of Japan in Electronic News (January 1, 1972) p.5.

Table 4-2

License Policy by Type of Company

	Receiving Tube Companies	Conglomerates	Successful Spin-Offs	Small Companies	Total
Licensed Frequently	1	5	1	0	7
Licensed Infrequently	1	1	2	4	8
Never Licensed	0	3	1	23	27
Total	2	9	4	27	42

Source: Responses to questionnaire; see Appendix B.

only be able to afford to pay royalties to one licensor; the three companies may try to "bid" for the license by offering more favorable terms.

Western Electric has a total of 179 foreign and domestic companies under license. (See Table 4-3.) Japan with 29 companies under license to Western Electric has the largest concentration of licensees outside the U.S. The total number of European licensees is only 26. Table 4-4 compares Western Electric's distribution of licensees to that of Fairchild and Texas Instruments. Western Electric has the largest number of foreign companies under license. It probably receives the largest foreign royalty income of any U.S. semiconductor company. Western Electric charges a maximum of 2.5 percent on the net selling price of products using its patents.[3] The license runs for five years after which it is negotiated again.

Unlike patent licenses issued by other American firms, Western Electric licenses indirectly supply technical assistance to foreign licensees. A valuable privilege extended only to representatives of companies holding Western Electric licenses is additional latitude in discussions held during visits to Bell Laboratories. Engineers from firms without licenses can visit Bell Labs, but they cannot discuss anything except published material. Foreign firms, particularly Japanese companies, have taken frequent advantage of the visitation privilege. British firms which have utilized the visitation privilege have not felt they gained much from the sessions.[4] The reason may be related to their lack of competence in the most advanced areas of semiconductor technology.[5]

Table 4-3

Geographical Distribution of Bell Systems Semiconductor Licensees

(As of April, 1974)

Country	Number of Licensees
United States	114
Japan	29
England	6
France	6
Germany	7
Italy	2
Netherlands	1
Switzerland	3
Sweden	3
Belgium	1
Australia	1
Canada	2
Hong Kong	1
India	1
Israel	1
Norway	1
Total	179

Source: Mr. Donald C. Mead, Manager, Patent Licensing, Western Electric, letter dated April 8, 1974.

Table 4-4

Geographical Distribution of Licensees of Major U.S. Patent Licensors, 1973

	United States (%)	Europe (%)	Japan (%)	Other Foreign (%)	Total Number of Licenses
Western Electric[1]	64%	14%	17%	5%	179
Fairchild[2]	50%	26%	24%	--	50
Texas Instruments[3]	50%	15%	35%	--	Unknown

[1]Source: Same as Table 4-3.

[2]Source: Electronic News numerous issues 1962-1974; 1972 10-K filing with SEC.

[3]Source: Distribution estimated from partial reports of Texas Instrument Licensees in Electronic News between 1965-1974.

Unable to question the Bell personnel authoritatively, the British representatives received less than the Japanese.

In 1973, Fairchild had 50 licensees evenly divided between domestic and foreign companies. (Table 4-4.) Table 4-5 documents the growth of Fairchild licenses and the corresponding royalty income. Fairchild has historically charged some of the highest rates for patent licenses with rates ranging from 4 to 6 percent. The stiff royalty rate actually discouraged some firms from taking out a license.[6]

Fairchild had a unique licensing agreement with Nippon Electric Corporation (NEC) of Japan for licensing the remainder of the Japanese industry. Starting in 1962, NEC licensed other Japanese firms with Fairchild sublicenses charging 4.5 percent; NEC received 10 percent of the total royalty revenue as a management fee.[7] The royalty rate was reduced to 4 percent in 1969.[8] Another interesting aspect of the NEC license was that it was a unilaterial license; Fairchild was not allowed to utilize its licensees' patents. In 1973 this license was renegotiated and changed to a cross-license.[9] The NEC license was important to Fairchild since it accounted for over 80 percent of its total royalty income.[10]

Texas Instruments has not been as aggressive as Western Electric and Fairchild in seeking licensees. (See Table 4-4.) It views a license as only a defensive instrument; it seeks to obtain legal recognition of its patents and cross-license agreements with other major manufacturers. Texas Instruments' royalty rates are less than Fairchild's. It originally charged its Japanese licensees 3.7 percent of the net selling price and later

Table 4-5

Fairchild Licenses and Royalty Income 1962-1973

	Cumulative Number of Licenses[1]	Annual Patent Royalty Income[2] ($ Million)
1962	2	---
1963	2	---
1964	6	---
1965	8	2.0
1966	12	---
1967	18	5.0
1968	20	---
1969	25	---
1970	36	9.0
1971	40	9.0
1972	44	6.0
1973	50	---

[1]Sources: Fairchild 1972 10-K report; discussion with Fairchild representatives; Electronic News reports of Fairchild licenses 1962-1973.

[2]Sources: 1965, 1967, 1970-71 reported in Electronic News; 1972 income from 1972 10-K report.

reduced the rate to 2.7 percent.[11] TI issued patent licenses to Japanese firms in return for being allowed to establish a joint-venture subsidiary in Japan.

4.b Know-how Licenses and Second Source Agreements

Know-how licenses and second source agreements transfer technology to foreign firms by providing them with direct technical assistance. There are several differences between these two types of agreements. First, second source agreements cover product technology while know-how licenses deal primarily with process technology. Second, second source agreements are limited in their scope to specific products. Know-how licenses can cover all phases of semiconductor technology but usually emphasize wafer fabrication technology. Third, second source agreements can transfer the most advanced product technology to the company second sourcing, but know-how licenses will not be granted for the most advanced process technology. The unstable nature of new processes make them ill-suited for transfer by license to another firm. American companies are also unwilling, as a general policy, to let other firms have access to their most advanced process technology. As stated earlier, new products can be copied only when the imitator has prior knowledge of the relevant process technology.

Only 4 American firms out of a total sample of 42 regularly agreed to know-how licenses with foreign firms. (See Table 4-6.) Of the four, Fairchild was the only firm with advanced technology which has frequently sold its process know-how to foreign companies. The reason for Fairchild's maverick behavior was partly explained by its heavy emphasis on R and D.

Table 4-6

Sale of Semiconductor Process Know-How by Type of Company

	Receiving Tube Companies	Conglomerates	Successful Spin-Offs	Small Companies	Total
Regularly Sold Know-How	1	2	1		4
Infrequently Sold Know-How	1	2	2	4	9
Never Sold Know-How		5	1	23	29
Total	2	9	4	27	42

Source: Responses to questionnaire; see Appendix B.

It was spending an estimated 16 percent of its semiconductor sales revenue on research in the early sixties and yet it was strongly committed to a policy of completely funding research internally.[12] Revenue from know-how agreements was used to support its large research budget. Most of the important transfers of know-how by Fairchild occurred while it was still a leader in new product development. As long as Fairchild continued to innovate, it could sell know-how to foreign competitors without hurting its market position.

While only a limited amount of information was collected on firms transferring know-how to foreign companies through second source agreements, several cases can point up the importance of this channel of transfer. In the previous chapter under the discussion of second sourcing, the case of Intel selecting a weak second source was cited. Intel sold its technology for an advanced MOS integrated circuit to a Canadian firm for a $2 million fee.[13] The Canadian firm became one of only three firms able to produce the advanced device.[14]

Another example of a second source transfer was between Advanced Memory Systems (AMS) and Siemens of Germany. AMS was the sole source supplier of Siemens for a bipolar integrated circuit. Siemens' policy required a second source so AMS transferred the product know-how to Siemens so it could become its own alternative source. Siemens received process specifications, test specification, master photomask sets, and 3 man-months of training at the AMS production facility in the U.S.[15] AMS was paid $200,000 by Siemens and given a cross-license allowing full access to Siemens patents.

4.c Licensing and the Transfer of Technology

Patent licenses are primarily for defensive purposes; it seems unlikely that they play any large role in the transfer of technology. The importance of know-how licenses and second source agreements is difficult to assess. The key to semiconductor technology is the process technology. This would seem to mean that know-how licenses which transfer process technology are more important than second source agreements. But process technology, as noted in the discussion of semiconductor manufacturing in Chapter 3, is more than simply knowing how to make a device. The learning economies which are related to production experience are critical to manufacturing semiconductors profitably. Significant learning economies are difficult to transfer on an inter-company basis in a one-time, short term exchange of production know-how. The problem was summarized by one semiconductor executive: "The complexity of the technology is not the critical factor (in transferring technology). Management is, and you can't transfer management."[16]

The problem of learning economies also affects the second source transfers. These transfers of a very narrow segment of product technology are important only where the foreign firm would have been unable to duplicate the product without outside assistance. This would only be the case for some of the more complex devices being marketed today. The second source transfer merely assists the foreign company in getting into production sooner than it would have otherwise. The advantage to the American firm is in having its product chosen as the standard for a foreign market.

The role that licenses play in the product cycle theory of trade[17] (as an intermediate method of participation in foreign markets preceding foreign direct investment and following exports) is neither supported nor strongly refuted by the patterns exhibited by the semiconductor industry. Firms mainly see licensing as either a means of avoiding costly litigation or as an opportunity to capitalize on their know-how in one time sales to foreign firms. The smaller firms which usually are the most innovative are the least prone to engage in licensing. The slow growth of the firms under license to Fairchild for its 1960 innovation, the planar process, points up another problem in trying to relate license activity to innovative activity. In the early sixties firms were reluctant to sign a license agreement with Fairchild; even today Fairchild probably has only one third of the total number of firms world-wide which are using the planar process under license.

Chapter 5

Direct Foreign Investment

Direct foreign investment activities of U.S. semiconductor companies have strongly influenced the pattern of U.S. semiconductor exports. Rather than follow the normal sequence of describing exports and then direct foreign investment, a better understanding of export patterns will be gained by first discussing direct foreign investment. (See Sections 7.b and 7.c for a discussion of the relationship of direct foreign investment and trade flows.)

The data presented in this section on direct foreign investment are based on a sample of 32 American semiconductor companies which had some form of foreign facility in 1973. (See Appendix A.) These firms accounted for more than 75 percent of U.S. factory sales in 1972 and nearly one third of total world sales.

Most of the major producers are included. To obtain the data over thirty interviews were held with representatives of companies and knowledgeable industry observers. The interview information was supplemented by company financial reports (especially the Form 10-K report filed annually with the U.S. Securities and Exchange Commission) and trade publication articles.

Foreign operations of American semiconductor companies can be grouped into three categories: (1) offshore assembly and subcontractor assembly primarily to supply the U.S. market; (2) point-of-sale (POS) assembly primarily to supply foreign markets; (3) complete manufacturing (wafer fabrication, assembly, and testing). Offshore assembly affiliates are set up in a foreign country to assemble U.S. manufactured sub-assemblies for export back to the U.S. The U.S. market is, by definition, the primary market served by an offshore assembly operation. (Foreign subcontractor assembly operations are included as a sub-class of offshore assembly even though they are not foreign direct investments. Subcontracting activities are an important step in the transfer of manufacturing activities overseas.) Point-of-sale facilities primarily supply foreign markets. The foreign operations with complete manufacturing are the only ones which process the silicon wafer completely from wafer fabrication through to final testing. These operations normally only serve foreign markets.

American foreign subsidiaries performing only assembly operations frequently serve both the U.S. market and foreign markets. This makes the identification of some assembly operations as either an offshore plant or a point-of-sale plant somewhat arbitrary. The designation of point-of-sale operation was assigned only if the affiliate performed final testing and the bulk of the sales were made directly to foreign customers.

Tables 5-1, 5-2, and 5-3 summarize the foreign activities for the 32 companies in the sample. The affiliates included in the tables are the current ones and do not include operations started and then ceased prior to 1972. Fairchild, for example, had an extensive European network of affiliates in joint ownership with an Italian firm. This was divested in 1968 and is not included. Activities shown are the current ones; affiliates which may have started with just assembly but currently perform wafer fabrication would only be included in the complete manufacturing category. These tables will be utilized in the subsequent discussions on offshore assembly,

Table 5 -1

Date of Establishment of Overseas Operations by Present Activity, Spring 1974

	Un-known	Before 1961	61	62	63	64	65	66	67	68	69	70	71	72-	Total
1. a. Offshore Assembly by U.S. Affiliate	3				1	1	1		3	4	13	5	2	14	47
b. Offshore Assembly by Subcontractor	2										1	6	1	3	13
2. Point-of-Sale Assembly	6		1			1		1	1	1	4	5	2	9	31
3. Complete Manufacturing		5			1			1	1	1	6	1		1	17
4. Total	11	5	1		2	2	1	2	5	6	24	17	5	27	108

Sources: Interviews with companies; company 10-K reports; Electronic News, numerous articles, 1957-1974.

Table 5-2

Date of Establishment of Overseas Operations by Location

	Un-known	Before 1961	61	62	63	64	65	66	67	68	69	70	71	72-	Total
1. Less Developed Countries															
Hong Kong	3				1						1	2		1	8
Korea						1	1			1		5	1		9
Taiwan									1	1	1				3
Singapore										2	2	2	3		9
Malaysia														11	11
Other South East Asia	1										1	1		3	6
Mexico	1								2		7	2		3	15
Other Latin America	1								1		1			5	8
TOTAL LDC	6				1	1	1		4	4	13	12	4	23	69
2. Developed Countries															
United Kingdom	1	3				1					4	2		1	12
France	1	1			1				1	1	1		1		7
Germany		1						1			1	2		1	6
Italy			1								2				3
Other EEC/ EFTA	3										2	1			6
Japan										1	1			2	4
Canada								1							1
TOTAL DC	5	5	1		1	1		2	1	2	11	5	1	4	39
3. TOTAL	11	5	1		2	2	1	2	5	6	24	17	5	27	108

Sources: see Table 5-1.

Table 5 -3

Present Activity of Overseas Operations by Location, Spring 1974

	Offshore Assembly by U.S. Affiliates	Offshore Assembly by Subcontractor	Point-of-Sale Assembly	Complete Manufacturing	Total
Less Developed Countries					
Hong Kong	5	3			8
Korea	5	4			9
Taiwan	3				3
Singapore	7	1	1		9
Malaysia	11				11
Other South East Asia	2	1	3		6
Mexico	12	3			15
Other Latin America	1	1	6		8
TAL LDC	46	13	10		69
Developed Countries					
United Kingdom			6	6	12
France			2	5	7
Germany			3	3	6
Italy			2	1	3
Other EEC/EFTA	1		5		6
Japan			2	2	4
Canada			1		1
TAL DC	1		21	17	39
TOTAL	47	13	31	17	108

Sources: see Table 5-1.

point-of-sale assembly, and complete manufacturing.

5.a Offshore Assembly

5.a.1 Size and Location of Offshore Assembly Operations

By 1973, the 32 U.S. firms in the sample had invested an estimated $380 million in 47 offshore assembly operations.[1] (The total U.S. investment in offshore assembly plants probably exceeds $450 million.) With one exception, the offshore assembly affiliates of U.S. companies in the sample are located in South East Asia and Latin America. (See Table 5-3). The South East Asian region was the first area where American semiconductor firms located offshore assembly operations. (See Table 5-2). Other American electronics manufacturers had previously located there, probably because of the low labor costs and the stable governments in the area; the semiconductor firms initially were following an already established pattern. After first locating subsidiaries in Hong Kong and Korea, U.S. firms established additional operations in Taiwan, Singapore, and Malaysia. The spread of U.S. companies through the area was mainly due to increasing wage levels in older offshore locations.

5.a.2 The Motive for Offshore Assembly

The primary reason American semiconductor companies establish offshore assembly operations is to lower direct labor costs. The natural divisions between wafer fabrication, assembly, and final testing allow the assembly phase to be located at a different facility from the remainder of the manufacturing operations. Assembly technology is quite readily transferred. There are no supply constraints on the location of an assembly plant other than adequate low cost labor and electrical power. Learning economies are not significantly affected by having multiple assembly facilities. In the most common form of manual assembly, assemblers can usually be taught the basic techniques in one day and be reasonably proficient in less than two weeks.

Wage rates for assemblers in the major offshore assembly areas are from 10 to 15 percent of U.S. wages. (See Table 5-4.) When assembly is transferred offshore, the lower wage rates can yield up to a 50 percent decline in total manufacturing cost. For example, the total manufacturing cost for an MOS integrated circuit in 1973 was approximately $1.45 per device with assembly done in Singapore. (See Table 3-4.) If the same device was assembled in the U.S., the total manufacturing cost would be about $3.00.

There are other factors which have affected the location of offshore activities. Y.S. Chang, in a questionairre sent to U.S. semiconductor firms, asked for a listing of the three most important factors which influenced offshore plant location.[2] Low wage rates ranked first followed in order of importance by the availability of trainable labor, the proximity to market, political stability, government incentives, and several other factors. Proximity to market was considered especially important for locating in Mexico.

Offshore assembly allowed U.S. companies to achieve a large reduction in their manufacturing costs without waiting for learning economies. Once one U.S. firm transferred assembly offshore, it became imperative for the balance of the industry to duplicate this move to remain competitive. Fairchild was the first U.S. semiconductor company to establish an offshore assembly plant. It set up operations in Hong Kong in 1963 and in Korea a year later. By 1969, 60 percent of semiconductor companies in the sample had set up an offshore operation. (See Table 5-5.)

Foreign firms, seeking to remain competitive with American firms, were forced to duplicate the American migration offshore. Y.S. Chang, in a study of the Japanese electronics industry, stated that "...the offshore production

Table 5-4

Hourly Wages for Assembly Workers by Country

	Year	Hourly Wages[1] ($)	Percent Change
1. United States	1966	2.50	
	1973	3.50	40
2. Hong Kong	1966	0.25	--
3. Korea[2]	1967	0.10	
	1974	0.15	50
4. Malaysia[2]	1973	0.15	
	1974	0.30	100
5. Mexico	1973	1.25	--
6. Singapore	1969	0.11	
	1974	0.30	170
7. Taiwan	1966	0.19	--

[1]Hourly figures were based on eight hour working shift.

[2]Adjusted for fringe benefits.

Sources: Interviews with semiconductor executives; Electronic News December 29, 1969, p. 4, March 27, 1967, p. 48, and March 25, 1974, p. 1.

Table 5-5

Annual Increase of Offshore Assembly

by Company for 32 U.S. Semiconductor Companies, 1963-1972

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1. Annual Number of Companies commencing Offshore Assembly	1		1		2	3	8	5	3	3
2. Cumulative Number of Companies with Offshore Assembly[1]	1	1	2	2	4	7	15	20	23	26
3. Number of Sample Companies in Existence	18	18	18	19	20	22	25	28	30	32
4. Cumulative Percentage of Companies with Offshore Assembly[2]	6	6	11	11	20	32	60	71	77	84

[1]Five sample companies have no offshore assembly.

[2]Row 2 ÷ 3

Source: Same as Tables 5-1, 5-2, and 5-3.

of Japanese semiconductor devices... (was) undoubtedly stimulated by (the) massive offshore production of the U.S. semiconductor firms."[3]

The large semiconductor companies, particularly the conglomerates and successful spin-offs, were primarily responsible for the growth of offshore assembly operations in the sixties. (See Table 5-6.) Since 1969, small firms also have operated in low wage countries. The relationship between the size of a company's total domestic semiconductor sales (millions of dollars, S_i) and the number of offshore assembly plants (A_i) was estimated by ordinary-least-squares (t statistic in parenthesis):

$$(5.1) \qquad A_i = 0.978 + \underset{(8.30)}{0.022}\, S_i \qquad \bar{R} = 0.66$$

The estimated relationship suggests that an increase of $50 million in U.S. sales is associated with an additional offshore operation though even a very small sales volume could support an offshore plant; companies with annual sales of as low as $1 million were forming offshore affiliates. (See Appendix A.)

5.a.3 Subcontract Assembly

Subcontract assembly operations started quite soon after Fairchild's initial ventures were formed in South East Asia. (Table 5-6 does not show these early subcontract operations.) Large companies were the first to use subcontract assembly as they attempted to remain competitive with Fairchild. The bulk of the subcontract operations today are associated with small companies. Subcontract assembly is an important way for small companies to gain access to low wage areas without having to make an investment in plant and equipment.

Table 5-8

Formation of Offshore Assembly Affiliates by Type of Company, 1963-1972

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	Un-known	Total
1. Large Companies												
a. Receiving Tube[1]							3		1	1		5
b. Conglomerates					2	3	6	2		2	1	16
c. Spin-off, Affiliates	1	1	1		1	1	3	2		2		12
d. Spin-off, Subcontractor							1			1	1	3
TOTAL, Large Company Affiliates and Subcontractors	1	1	1	0	3	4	13	4	1	6	2	36
2. Small Companies												
a. Small Company, Affiliates							1	1	1	8	3	14
b. Small Company, Subcontractor								6	1	2	1	10
TOTAL, Small Company, Affiliates and Subcontractors							1	7	2	10	4	24
3. TOTAL Offshore Operations	1	1	1	0	3	4	14	11	3	16	6	60

[1]Includes RCA

Source: See Table 5-1.

Some firms have used subcontractor assembly plants while their plant was under construction to provide interim production capacity. Once their plant was completed, the workers transferred to the new plant with no interruption of output.[4]

5.a.4 Offshore Assembly and the Distribution of Manufacturing Costs

The distribution of manufacturing costs between fabrication and assembly has changed drastically because of two major factors. First, there was the initial reduction in direct labor costs expended for assembly. When assembly was performed in the U.S., direct labor costs of assembly were the largest part of total manufacturing costs. But after assembly was transferred to a low wage country such as Singapore, most of the labor costs were redistributed so that overhead costs (indirect labor and ancillary services) became the largest share. (See Table 5-7.)

The second impact on the distribution of costs is a continual increase in the share of total manufacturing costs represented by assembly costs. This effect results from improving production yields, particularly in wafer fabrication. This can be seen by reexamining equation 3.1. First, assume that losses are taken only at wafer electrical test; Y_1, Y_3, Y_4, the yields at wafer fabrication, chip bonding and wiring, and final electrical test respectively, are assumed to be 100 percent. (In fact these yields are about 80 to 90 percent for a mature process. See Table 3-3.) Second, wafer fabrication costs C_1 and C_2 are combined into a new variable, W_t, the total wafer fabrication costs. Assembly costs C_3 and C_4 are redistributed in two variables: A_1, the labor costs of assembly, and A_0, all other costs of assembly. The revised equation for total manufacturing costs per chip is:

Table 5-7

Distribution of Semiconductor Manufacturing Costs

a. Distribution of Direct Labor Costs (Percent):

	Assembly in the U.S.	Assembly in Singapore
Wafer Fabrication	15	60
Assembly	85	40
Total	100	100

b. Distribution of Total Manufacturing Costs (Percent):

	Assembly in the U.S.	Assembly in Singapore
Manufacturing Overhead	30	50
Direct Labor	60	20
Materials	10	30
Total	100	100

Sources: Distributions calculated from data supplied by J.P. Ferguson Associates, Los Altos, California.

$$\text{(5.2)}\quad \text{Total Cost Per Chip} = \frac{W_t}{Y_2 N} + A_1 + A_o$$

Then stating assembly costs as a proportion of total manufacturing costs:

$$\text{(5.3)}\quad \frac{\text{Assembly Costs}}{\text{Total Manufacturing Costs}} = \frac{A_1 + A_o}{\frac{W_t}{Y_2 N} + A_1 + A_o}$$

Assuming that assembly costs remain constant as the yield in wafer electrical test (Y_2) increases, the proportion of total costs represented by assembly will increase. Rising assembly labor costs (A_1) will have the same effect. Since yields are continually improving and foreign labor costs have been increasing relative to U.S. labor costs, it may be inferred that foreign content of devices assembled offshore has been increasing as a percentage of total landed cost. (Landed cost is the cost of the imported, assembled device prior to final mark-up.) Table 5-8 shows the U.S. content of reimported semiconductor devices from offshore plants as a percentage of total import value. The U.S. share has been declining or conversely the value added by foreign assembly has been increasing relative to the total cost of the finished device.

Table 5-8

U.S. Content of Reimported Semiconductor Devices from Offshore Plants[1]

(Percent)

	1969	1970	1971	1972	1973
Imports:					
All Semiconductors	0.59	0.41	0.45	0.40	0.30
Transistors	----	0.49	0.46	0.38	0.33
Diodes & Rectifiers	----	0.38	0.37	0.31	0.19
Parts	----	----	----	0.11	0.04
Integrated Circuits	----	0.55	0.47	0.43	0.32

[1]Proportion of U.S. content relative to total value of U.S. imports from all sources.

Source: 1969, U.S. Department of Commerce data presented in Electronic News. (September 3, 1973), p. 4; 1970-1973 U.S. Department of Commerce, unpublished data.

The changing distribution of costs will affect the duties U.S. companies pay on the reimported devices. Provisions of the U.S. Tariff Schedule give favorable treatment to the importation of semi-finished semiconductors assembled from U.S. manufactured parts. Tariff Items 806.30 and 807.00 of the Tariff Schedules of the United States provide for duty to be paid only on the value added by foreign assembly.[5] Included in the computation of the foreign value added or constructed value are materials, labor, a markup for overhead, an estimated profit, all net of value of the U.S. content.[6] The ad valorem rate of the tariff is between 5 and 8 percent. (Foreign duties can be ignored since most offshore plants are established in duty-free trade zones.) As the value added by foreign assembly increases relative to the U.S. content, the duty paid by U.S. firms on the reimported devices will increase as a proportion of total product value.

Transportation costs are approximately 5 percent of the total manufacturing costs for a device in the mature stage of the product life cycle. (For devices in earlier stages of the product life cycle transportation costs would represent a smaller share of total manufacturing costs.) Reduction in the duties achieved through the use of Items 806 and 807 act to offset the transportation expenses incurred in using offshore facilities. Foreign firms importing devices into the U.S. from assembly facilities in LDC's do not receive the benefits of the special tariff provisions.

5.b. Point-of-Sale Assembly

The classification of foreign subsidiaries into point-of-sale (POS) assembly and offshore assembly was based on the destination of assembled output. However, differences between the two types of foreign operations go beyond just destination of output. First, POS assembly can be considered as an intermediate stage of backward integration of manufacturing technology in a foreign affiliate. U.S. companies assemble and test devices in POS affiliates prior to the extension of production to wafer fabrication. Second, POS assembly is primarily located in developed countries. Labor costs have influenced the selection of a location; but they have not been a major determinant. The POS assembly plants are located where they can best assist the U.S. firm's penetration of foreign markets. Note that the distinction between the two types of assembly is not based on the type of technology used for assembly.

5.b.1 Number and Location of POS Assembly Affiliates

Thirty one of the overseas operations of U.S. semiconductor companies sampled were classified as POS assembly. (See Table 5-3.) Since some offshore assembly operations of U.S. companies supply foreign markets as well as the U.S., the total number of facilities directly serving foreign markets may be considerably larger.

Two thirds of the POS assembly operations are located in developed countries. (See Table 5-3.) This reflects the main purpose of POS plants: the increased market penetration of the major foreign semiconductor markets in Europe and Japan. The ten POS assembly affiliates located in less developed countries primarily export their output to Japan and Europe.

The large conglomerates are the major type of American semiconductor company establishing POS facilities. (See Table 5-9.) Between 1961 and 1972, these firms established 28 POS affiliates; 14 of these affiliates subsequently acquired wafer diffusion capability. Beginning in 1970 other types of U.S. companies also established POS affiliates primarily in Europe. It should be noted that 1970-71 were recession years for the domestic U.S. semiconductor industry. But in Europe and Japan demand for semiconductors continued quite strong. This was one factor which caused U.S. companies to establish POS assembly facilities during this period.

Point-of-sale assembly operations were started sooner than offshore assembly, but grew at a slower rate. (See Table 5-10.) The slower rate of growth was caused by the entry of small, spin-off companies into the U.S. industry. These firms lacked the financial resources to establish both POS facilities and offshore facilities. The competitive U.S. market forced these firms to gain access to offshore operations.

5.b.2 Factors Influencing the Establishment of POS Assembly Operations

A variety of factors influenced American firms to transfer production abroad to serve foreign markets. Some special factors will be discussed in the section on foreign facilities performing wafer fabrication. This section will deal with general economic factors. This discussion will not pertain to Japan since American companies were prevented from having open access to the Japanese market.

There were five general factors which influenced the decision of American firms to initiate assembly in the European market. First, the absolute size of

Table 5-9

Formation of Point-of-Sale Affiliates by Type of Company

	Unknown	Before 1960	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	Total
1. Large Companies																
a. Receiving Tube							1						1		1	3
b. Conglomerate	2			1					1	1	1	3	1	1	3	13
c. Spin-off	3												3		2	8
Total, Large Company	5			1			1		1	1	1	3	5	2	6	27
2. Small Companies	1											1			2	4
3. Total Point-of-Sale Operations	6			1			1		1	1	1	4	5	2	9	31

Source: Same as Table 5-1.

Table 5-10

Number of Companies Commencing POS Assembly Operations (32 U.S. Semiconductor Companies)

	Before 1960	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1. Number of Companies Commencing POS Assembly 1/	3					1	1		1	2	5	2	2	2
2. Cumulative Number of Companies with POS Assembly	3	3	3	3	3	4	5	5	6	8	13	15	17	19
3. Number of Sample Companies in Existence	16	16	16	16	18	18	18	19	20	22	25	28	30	32
4. Cumulative Percentage of Companies with POS Assembly 2/	19	19	19	19	17	22	28	26	30	36	52	54	57	63

1/ Includes complete manufacturing facilities

2/ Row 2 ÷ Row 3

Source: Same as Table 5-1.

the foreign market became significant by the middle sixties. American firms were afraid of trying to support their market position completely from external sources. The tariff barriers established by the EEC and EFTA were the second important factor. The effects of tariffs on U.S. export prices will be detailed shortly. Nontariff barriers were also important. For example, the French had administrative quotas on imports of devices which were also manufactured in France. The third factor was the existence of American firms already operating manufacturing facilities in the European market. By the middle sixties Texas Instruments and several other American firms had already initiated production in Europe; the reasons for their earlier entry into foreign production will be discussed in Section 5.c. The presence of these American firms already in the market put pressure on exporting firms also to transfer production to a foreign affiliate.

The fourth factor affecting the decision to enter into foreign manufacturing was the importance of the European military end-use market for U.S. companies. Though small relative to the American military market, it consumed an important share of U.S. exports. Advancing national security reasons, the British and French governments pressured U.S. firms to take on more of the character of domestic producers.

A final factor was the evolution of semiconductor technology. Integrated circuits had evolved from single circuit devices to the incorporation of entire systems on a single chip. The design of complex integrated circuits became a major task of the semiconductor manufacturer. Greater coordination between semiconductor supplier and buyer became necessary.

The typical sequence of establishing production in a foreign subsidiary starts with the transfer of design capability. This is an easy step to take since it involves a limited amount of investment and mainly requires the hiring of an engineering staff. The balance of the production process is integrated into the foreign subsidiary in the opposite sequence of actual production. Final testing of discrete devices or simple integrated circuits is transferred next since it, too, is a simple operation requiring a small investment. Assembly capability usually is added to testing. This forms a point-of-sale operation. The final stage to be added, wafer fabrication, requires a special set of conditions to support its transfer. These are discussion in Section 5.c.

5.b.3 Effect of POS Assembly on Tariff Burden

Depending on the location of the POS plant, tariffs can either be reduced or completely eliminated. The avoidance of the Japanese tariff is accomplished by locating the POS plant in a developing country. Imports into Japan from an affiliate located in a LDC are duty-free. The offshore subsidiaries of American firms have also been used to export directly to Japan. (This type of export will be discussed in Section 7.b.) Signetics' offshore facility in Korea, for example, was the largest exporter of integrated circuits to Japan in 1969.[7] Avoidance of the EEC tariff is accomplished by locating assembly in the Netherlands Antilles. In both cases American firms obtain the additional benefit of lower assembly costs.

Point-of-sale plants within the EEC lower the tariff burden since the imported sub-assemblies are only valued at the cost of wafer fabrication. Wafers imported into the EEC represent approximately 50 percent of the final value of the finished devices (prior to mark-up for final sale). American firms can reduce their final costs in the EEC by about 7 percent through exporting sub-assemblies to the EEC for final assembly. (This assumes that the labor costs are identical in the U.S. and the EEC.) Parts exported directly to the EEC have been increasing (see Table 7-6) but not very rapidly. The reason for this can be seen by noting that if a U.S. firm ships the sub-assemblies offshore for assembly and from there to Europe, the final costs are 25 percent less than for the direct export to Europe of complete devices (ignoring differences in transportation costs) and 18 percent less than for the direct export of parts for assembly.

A final note about the EEC tariff: the tariff rates are fully assembled devices and sub-assemblies (diffused wafers for example) are identical. Therefore, the EEC effective rate of protection is identical with the nominal rate for semiconductors. There is no additional incentive to import sub-assemblies into the EEC due to any escalation in the effective tariff rate over the nominal rate.

5.b.4 Effect of POS Assembly on Pricing

The presence of a POS assembly affiliate in the European market allows the American parent greater flexibility in its marketing strategy. The additional latitude takes two forms: first in determining the source of its product and second in establishing a market price. The alternative ways of supplying the European market will be discussed in Section 7.c. This section will outline the problems facing American firms with regard to setting their prices in Europe.

As discussed in Section 2.d, European semiconductor firms tend to follow a different strategy from American firms with regard to product pricing. While American firms tend to cut prices to stimulate market demand, European firms tend to decrease their prices simultaneously with increased market demand. (Recall that price decreases in this industry are associated with cumulative production volume.) The price differential between the two markets will be substantial during the early phases of the product life cycle. Later, as American prices stabilize and European prices continue to decline, the price differential will narrow. Robert Freund, in a paper discussing competition and innovation in the U.S. transistor industry, states that "...(price discrimination) was practical only for technically advanced and relatively new products. Under these conditions the same product or equivalent quantity levels would sell in Europe at 30 percent to 40 percent higher than in the U.S."[8] Thus an American firm exporting a new device to Europe follows a policy of price discrimination.

The presence of a POS affiliate in the European market will assist the American firm in achieving its objective of price discrimination. This can be illustrated by first assuming that the relative price differential for a particular device is quite large and then modifying the assumption assuming that the differential becomes quite small.

Let P_a be the American firm's price for a device in the United States. Let T be the ad-valorem tariff rate on that product. Let P_e be the European market price for the device; it is assumed to be higher than the U.S. market price. The non-discriminating American firm would sell its exported products in Europe at $P_a(1+T)$. (Shipping costs are assumed to be negligible at this early stage of the product life cycle when production costs are at their highest.) Demand is assumed to be inelastic since the major purchasers of the devices would be militar equipment suppliers. (This follows Tilton's assumptions.) Given this set of circumstances, the American firm will increase its European price until the marginal revenue in the two markets equates. By discriminating between the two markets, the American firm is able to capture additional rent on the technological leadership embodied in its exports.

European firms seemingly could source directly from the American parent and avoid the higher European price. But there is no evidence that European firms do this. This can be partly explained by the nationalistic policies pursued by the European electronic manufacturers which lead them to prefer to source directly from domestic suppliers. This policy to source only locally in turn pressures the American firm to establish a POS affiliate to service its European customers. In taking on the appearance of a domestic supplier, the American firm is able to import the assembled devices from the parent and set the price at P_e. If assembly is performed in Europe rather than elsewhere, the rent obtained by the parent does not diminish. On the contrary, its profit margin can increase (if the assumptions defined in the preceding section concerning the tariff burden are made). The increased profit margin results from a reduction in the tariff burden. The presence of a POS facility is not a necessary requirement to allow the American firm to engage in price discrimination. But given the divergent characteristics of the two markets it simplifies the problem of separating the markets.

A U.S. firm which sells a device which is in the mature stage of the product life cycle in both the U.S. and Europe faces a different type of problem in settings its prices in the respective markets. The price differential between the two markets will have narrowed considerably; European firms are now major suppliers and the end-markets are assumed to have broadened beyond just the military ones. Assume that the price of the device has stabilized in both markets; learning economies are no longer having a significant impact on manufacturing costs and in turn on market prices. The prices charged in the two markets by an American firm should differ only by differences in market supply characteristics (demand elasticities will be similar) and the effects of any tariffs and shipping costs (now assumed to be a factor since manufacturing costs have fallen over the product life cycle). Let P_a be the American market price. Let P_e be the European market price. If P_f, the American export price in Europe (where P_f equals $P_a(1 + T) + S$, the shipping costs), exceeds P_e, the American firm is priced out of the market. The American firm must reduce its European price to remain competitive. That is, it must discriminate against its American customers. But if the American exporter attempts to reduce his European price, its American customers will demand a lower price equivalent to $P_e \div (1+T)$.[9] The American firm must decouple his price in Europe from his domestic selling price. To solve this problem, the American firm exports the device in semi-finished form to a European POS assembly operation. This reduces the tariff burden allowing a reduction in its European price due to lower total costs. (A further reduction could be achieved through indirect export from an off-shore facility to Europe.)

5.c Complete Manufacturing

There have been 17 cases in the sample of U.S. semiconductor companies' foreign operations where the backward integration of manufacturing operations included wafer fabrication. (See Table 5-11). The fully integrated facilities are located exclusively in the EEC and Japan. (See Table 5-3). The large conglomerate companies are the primary type of American firm which have transferred wafer fabrication technology overseas.

Learning economies gained from long experience with a process are the most difficult part of the production process to transfer. Only firms which had multiple wafer fabrication plants in the U.S. have transferred wafer technology to their foreign affiliates. To minimize the losses in learning economies, firms usually select a well-established production process for transfer. Several firms reported that they had transported an entire production facility from the U.S. to the foreign affiliate when initially commencing wafer fabrication. Even when a transfer is being made to an already operating wafer fabrication facility, firms will not transfer a new process until sufficient experience has been obtained at the U.S. facility. Only processes which are well controlled and stable will be transferred.

Wafer fabrication plants have constraints on where they can be located. The critical limitation is the availability of chemicals and de-ionized water in sufficient quantity and quality. Firms have found that even transferring a mature process to Europe can be difficult. Enough of the raw material inputs vary in composition to cause serious difficulty in some instances in obtaining comparable production yields to those in the U.S.

Table 5-11

Number of Foreign Affiliates Presently Doing Wafer Fabrication and Assembly,

by Date of Establishment

	Unknown	Before 1960	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	Total
A. Large Companies																
1. Receiving Tube											1					1
2. Conglomerates		3	2			1			1	1		5			1	14
3. Successful Spin-Offs												1	1			2
Total		3	2			1			1	1	1	6	1		1	17

Source: Same as Table 5-1.

5.c.1 Factors Affecting the Transfer of Wafer Fabrication Technology

The general factors which affected the decision to invest in a foreign assembly plant were discussed in the previous section. This section will discuss the special economic factors involved in the 17 transfers of wafer fabrication offshore. These are presented on a company basis:

a. Texas Instruments (TI)

TI was the first American firm to transfer wafer technology abroad. In 1957 it established a British affiliate and by 1959 was diffusing wafers on a limited scale in Britain. TI was invited by the British Government to establish the plant to supply military semiconductor devices.[10] TI also received a contract from the British Government in 1961 to establish integrated circuit production as "rapidly as possible."[11] The establishment of its wafer fabrication facility in France in 1960 was a response not to the French Government but to IBM. This was an extension of the special relationship which then existed between the two firms in the U.S. In both the British and French cases, however, TI realized that there were long-run benefits to be attained from their early entry. In particular it believed that the demand of European computer manufacturers for semiconductors would grow significantly in the early sixties.

b. ITT

ITT has three affiliates in Europe performing wafer diffusion. ITT cannot be treated as an American company transferring technology to Europe since the company's semiconductor activities were first established in Europe. ITT expanded from its European base into the

American market.

c. Motorola

Motorola transferred fabrication into France in 1969. This transfer and the motives for it will be discussed in detail in Section 5.c.2.

d. International Rectifier (IR)

IR has two diffusion facilities overseas. The company went abroad very early; first going into Britain in 1959 and Japan shortly thereafter. IR made this unusually early move abroad due to the competition it faced in the domestic market. IR produced devices used in heavy power equipment applications; this brought it head-on against GE and Westinghouse. Unable to grow against the two giants it moved abroad.

e. Signetics

Signetics established a small diffusion facility in Scotland in 1969. This transfer was caused in part by a shortage of engineering and technical talent in the San Francisco Bay area where Signetics is based. Signetics needed to expand and sought to use available talent in England. Initially output from the plant was shipped entirely back to the U.S.; later the plant was used to support Signetics' penetration of the European market.

f. National Semiconductor

National set up a diffusion facility in Scotland in 1970 for reasons nearly identical to those of Signetics.

g. Westinghouse

Under pressure from the French Government to increase the amount of processing done locally, Westinghouse transferred wafer diffusion in 1967. This facility was supported by Westinghouse's substantial power equipment operation in France.

5.c.2 Motorola's Investment in France

To conclude the discussion of U.S. semiconductor foreign direct investment, the Motorola investment in France will be described. Motorola's semiconductor division was formed in early 1962. The first overseas sales office was opened in Europe the following year. Prior to the establishment of the European office, Motorola's international semiconductor sales had been handled by 22 foreign distributors.

Around 1964 Motorola made the decision to establish a plant in France. Motorola had been primarily an exporter of discrete devices to Europe; an area of semiconductor technology that where European firms were rapidly overtaking the U.S. lead. Discrete prices in Europe were declining sharply. In these circumstances, Motorola found that the tariff and non-tariff barriers were becoming a problem. France was selected as the site because it had a large market for semiconductors and, more importantly, because it had the most severe non-tariff barriers in Europe.[12]

Motorola's entry into France was approved by the French Government in 1966. The plant was to be in operation by late 1967. In the interim Motorola built a warehouse facility in Switzerland to improve its delivery time to customers. (See Section 7.c which discusses the impact of this facility on the patterns of European semiconductor trade.) Motorola started testing operations in its French plant in September 1967. Assembly was added in 1968 and wafer diffusion finally introduced in 1969. In 1974 Motorola invested an additional $3.4 million to expand the wafer production capacity and upgrade the process technology.[13]

5.d Effects of Direct Foreign Investment on Employment

Direct foreign investment by U.S. semiconductor companies has had a major impact on the world-wide distribution of employment in the industry. Since about 1970, U.S. firms have employed a larger number of workers in foreign plants than in domestic plants. The establishment of the offshore facilities has had an especially important effect on the relative distribution. While the total number of production workers in the U.S. did not change appreciably between 1965 and 1972, employment in offshore facilities grew substantially and was nearly 120,000 by 1974. (See Table 5-12. These employment figures have been estimated from individual company foreign employment data and the total number of foreign affiliates.)

One can postulate three possible effects that direct foreign investment has had on employment in the U.S. semiconductor industry. First, the transfer of assembly operations offshore has probably upgraded the average level of production employee skills required in the domestic industry. Second, is the possibility that foreign labor has substituted for U.S. labor (or possibly U.S. capital). Third, if the savings in production costs resulting from lower foreign labor costs are passed on to consumers, then the U.S. and world employment in the industry has probably benefited from the increased demand.

The first of these effects, the change in occupational mix of the industry, has been documented by surveys of the industry's labor force. (See Table 5-13.)

Table 5-12

Employment in the U.S. Semiconductor Industry and U.S. Offshore Assembly Plants, 1963-1972

	Production workers in U.S. Establishments (Thousand)	Total Employment in U.S. Establishments (Thousand)	Estimated Employment in Offshore Plants (Thousand)
1963	37.5	56.3	2.1
1964	37.9	55.3	4.3
1965	48.7	67.4	6.5
1966	59.1	82.2	8.6
1967	57.9	85.4	15.1
1968	60.5	87.4	30.1
1969	69.3	98.8	66.7
1970	60.3	88.5	74.8
1971	45.5	74.7	84.6
1972	54.8	84.6	89.1

Source: U.S. industry employment, Annual Survey of Manufactures, Industry Profiles, U.S. Dept. of Commerce, Washington, D.C., Sept. 1973, p. 230; offshore employment estimated by the U.S. Department of Commerce based on data supplied by author.

Table 5-13

Occupational Distribution of the
U.S. Semiconductor Industry 1964-1971

(Percent)

Occupation		Percent of Total Labor Force		
		1964		1971
A. Executive, Administrative, Technical, and Clerical		31		52
1. Executive	2		5	
2. Administrative	6		8	
3. Technical	16		27	
4. Clerical	7		12	
B. Plant and Custodial Workers		69		48
1. Skilled	8		9	
2. Semi-skilled and unskilled	61		38	
C. Total		100		100

Source: U.S. Department of Commerce, unpublished report, based on a 1964 Business Services and Defense Administration Semiconductor Growth Study (unpublished) and a 1971 Bureau of Labor Statistics Occupational Survey (unpublished).

Between 1964 and 1971, semi-skilled and unskilled workers declined from 69 percent of the total industry labor force to 48 percent. Skilled workers remained a constant proportion of the labor force while technical occupations increased from 16 percent to 27 percent.

Given the change in the occupational structure of the semiconductor industry and the rapid growth of foreign employment in offshore facilities, it seems likely that, across firms, changes in U.S. employment of semi-skilled and unskilled production workers are negatively correlated with changes in foreign employment. But the available empirical data is not adequate enough to measure the net influence on U.S. labor resulting from the negative effects that substitution would imply and the positive effects of increased labor skills and increased demand.

5.e Adaptation of Semiconductor Technology

The final question to be examined in this chapter is whether American semiconductor firms adapt their technology to foreign conditions when they transfer manufacturing know-how abroad. Only adaptation of production technology will be considered since product related technology is not relevant. (See Section 3.a for the distinction between product and process semiconductor technology.) The discussion will cover both direct foreign investment and licensing transfers.

Adaptation of a production process to foreign conditions would typically imply that a firm modifies the ratio of factor inputs in response to a different set of factor prices, or in response to a change in the scale of operation, or possibly a modification in the type of production equipment. Semiconductor process technology is not modified in the short-run to any of these factors. American firms interviewed for this study stated they did not adapt their process technology to differences in foreign factor market conditions.

What American firms have typically done, and Tables 5-1, 5-2 and 5-3 reflect this, is to select for transfer from the different stages of production those phases which are most appropriate for the host country conditions. In labor surplus regions, assembly operations have been established since this stage of production is labor intensive. As a result, the capital-labor ratio is much higher in the U.S. semiconductor industry's domestic operations than in its offshore assembly operations.[14] The capital-labor ratio for U.S. offshore operations is estimated to be between 0.2 and 0.3.[15]

There are several assembly methods utilized by American firms. These can roughly be divided into manual and automated techniques. About 70 percent of all semiconductors shipped by U.S. companies in 1970 were manually assembled.[16] But in the offshore plants located in developing countries the manual assembly technique is the only one utilized. American firms have selected their most labor intensive production operation for transfer into the labor surplus areas.

Wafer fabrication, relative to the assembly phase of production, is capital intensive. It has been transferred to developed countries because, among other reasons, firms find the necessary supplies of raw material inputs and the engineering personnel to staff the facility.

In the developed country markets they have entered, American firms have not adapted their process technology to local conditions. In the interviews done for this study, nearly all the firms which had established wafer fabrication in Europe or Japan mentioned that their initial facility usually was previously set-up in America and transferred intact to Europe.

The capital-labor inputs to the wafer fabrication process were considered to be insensitive to factor price differences between developed countries. Adjustments in the production process were limited to process variables which had to be adjusted for changes in raw material inputs.

The selectivity applied to direct foreign investment transfers carries over to licensing. Firms which granted know-how licenses also selectively sold their process know-how to licensees. Westinghouse, for example, limited the process technology it would sell to India to only the most routine processes. This was to insure that the transfer would succeed. Again, however, the capital-labor inputs were not adapted to India's factor endowment. Rather the selection took into account the level of labor skills required to successfully operate a wafer fabrication facility.

Chapter 6

Exporting

U.S. exports of semiconductors transfer technology to foreign companies in several ways. They allow foreign firms to have access to advanced product technology. If the foreign firms have the necessary process technology, they can imitate or second source the product technology. Exports of complex integrated circuits enable foreign electronic systems manufacturers to incorporate American systems design technology into their products.[1] The major limitation to the transfer of semiconductor technology through the medium of exports is that process technology is not transferred. Direct foreign investment and know-how licenses are the only ways process technology can be transferred abroad by American firms.

The export market went through two distinct phases of development. Prior to 1965, it was a relatively minor market segment; but in 1965 export sales for the first time exceeded 5 percent of total U.S. factory sales.
After discussing the somewhat different influences upon
the volume of semiconductor exports in the period preceding 1965 and in
the post-1965 period, the composition of semiconductor trade will be analyzed.

6.a The Export Market: Pre-1965

In 1960, nearly ten years after the start of commercial semiconductor production in the U.S., semiconductor exports were less than 2.5 percent of factory sales.[2] During the next five years they steadily increased, reaching a level of $82 million or almost 10 percent of factory sales in 1965. There are several reasons why the export market remained relatively small prior to 1965. One was the relatively small consumption of semiconductors abroad. Table 6-1 compares the consumption of semiconductors in the major foreign markets of France, Germany, United Kingdom, and Japan to consumption in the U.S. Foreign consumption of semiconductors remained less than one third of U.S. consumption until the middle sixties.

A related factor was the difference in the relative importance of different end-use markets. The U.S. industry was concentrating primarily on supplying the military and computer markets. (See Table 2-2.) While supplying these markets, they focused most of their attention on the creation of new technology. Little effort was made to develop new markets for their products.

The pattern of semiconductor consumption in foreign markets was decidedly different from that in the U.S. The major foreign end-use markets were the

Table 6-1

Consumption of Semiconductor Devices in Major Foreign Markets[1], 1956-1972

	1956	1960	1965	1970	1972
United Kingdom	$ 2	$28	$72	$	$210
France	2	27	67	420	114
Germany	3	25	52		218
Japan	5	54	132	420	742
Total Consumption, Major Foreign Markets	12	134	323	840	1284
United States Consumption	80	560	1064	1547	1708
Ratio Foreign/U.S. Consumption	15%	24%	30%	54%	75%
U.S. Exports ($M) to all Developed Countries	$2	$15	$75	$249	$424

[1] In 1972 Britain, France, Germany and Japan consumed approximately 75 percent of the free world semiconductor production excluding the U.S.; in earlier years the percentage would be even higher.

Sources: Years 1956 and 1960 estimated from data supplied by John E. Tilton; 1965 from Anthony Golding, "The Semiconductor Industry in Britain and the United States: A Case Study in Innovations, Growth and the Diffusion of Technology" (Ph.D. dissertation, University of Sussex, 1971) p. 138; and 1970 estimated by J.P. Ferguson Associates; 1972, U.S. Department of Commerce, unpublished data.

industrial and consumer. These markets emphasized applications where reliability and performance were secondary to price in deciding whether to use semiconductors or not. Compared to the U.S. military end-use market, the foreign ones were relatively small and, in the case of Germany and Japan, nonexistent.

The difference in the composition of the U.S. and foreign end-use markets meant that the U.S. semiconductor firms were technically superior in areas where the foreign markets were relatively small. U.S. exports tended to be limited to specialized markets. Silicon transistors, for example, were exported to Britain in the late fifties principally for use in manufacturing missiles.[3]

During the pre-1965 period, what interested American firms in exporting were the higher prices they could charge foreign customers. The rapid price declines which characterized the American market did not begin in Europe until around 1964.[4] The price differential which developed between the domestic and foreign markets made exports very profitable. Foreign tariffs were not a major barrier to U.S. exports because of the specialized nature of the foreign demand.

6.b The Export Market: Post-1965

In the period after 1965, exports grew relative to the domestic end-use markets. By 1970 they accounted for nearly a quarter of U.S. factory sales. During this period of expansion, the nature of the export market changed. The changes reflected alterations in the structure of the foreign markets as well as the domestic market.

Foreign semiconductor markets evolved in several ways. First, their aggregate consumption of semiconductors began to reach significant levels. (See Table 6-1.) Second, prices no longer declined gradually; pricing policies, though still not as aggressive as American, followed the more traditional pattern of rapid decline followed by relative price stability. For example, prices for discrete devices in Europe fell rapidly in 1964 and again in 1966.[5] Because of the change in general pricing policies, tariffs became a problem for U.S. firms attempting to export into foreign markets and remain competitive in their prices. Non-tariff barriers also became important. The French market was exceedingly difficult to penetrate via exports because of quotas or even outright prohibition on the import of certain products. (See Table 6-2.) Before 1974, Japan also had quotas on certain types of imports.

Paralleling the maturing of foreign markets, the U.S. industry experienced two fundamental changes which influenced the composition and level of U.S. exports. First, the establishment of offshore assembly and point-of-sale assembly operations increased the export of semi-finished semiconductors. The exports to offshore operations were a particularly important change in the export pattern. The effect of offshore operations on trade flows will be discussed in the next chapter. Second, the U.S. industry changed in terms of the primary end-markets it served. (See Section 2.c.) As the industry broadened the applications for semiconductors, the military end-use market declined in importance. (See Table 6-3.) Consumer and industrial uses became the major new markets. These end-use markets were also the largest sectors of foreign semiconductor end-use markets. This increased the number of foreign markets American semiconductor companies could penetrate.

Table 6-2

Trade Restrictions, 1973, Selected Countries

Country	Type of Device	Tariff on Imports from the U.S.	Restrictions on Imports from the U.S.
Japan	transistors	8%	
	integrated circuits	12%	IC's which contain more than 200 elements cannot be imported without special permission.[1]
France	transistors	17%	Unofficial quotas exist.
	integrated circuits	17%	Unofficial quotas exist.
Germany	transistors	17%	
	integrated circuits	17%	
Switzerland	transistors	2%	
	integrated circuits	2%	

[1] Lifted in 1974.

Source: U.S. Department of Commerce, Country Market Survey, November 1973, for representative countries.

Table 6-3

Distribution of Semiconductor Sales Between Military and Nonmilitary Markets by Geographical Area

Country	Year	Percent Military	Percent Nonmilitary
United States	1960	50	50
	1966[1]	30	70
	1972[2]	24	76
Japan	1972[3]	--	100
Western Europe	1972[2]	14	86

[1] OECD, Electronic Components, p. 26.

[2] J.P. Ferguson, Associates, Los Altos, California.

[3] U.S. Department of Comerce, Country Market Survey: Japan, November 1973.

6.c Composition and Level of U.S. Semiconductor Trade

U.S. exports of semiconductors increased from $82 million in 1965 to $848 million in 1973, a period during which total factory sales (domestic production plus exports) increased from $1,122 million to an estimated $2,400 million. (See Table 6-4.) The major product areas which accounted for the substantial growth were exports of integrated circuits and semiconductor parts. (See Table 6-5.) Semiconductor parts include unprocessed wafers, wafers processed but unsplit, and packaging materials. These items were primarily exported to American offshore assembly and POS assembly operations. Exports of semiconductor parts grew from less than 30 percent of total exports in 1967 to about 50 percent by 1973; this amounted to an increase of $381 million over the 1967 level of $42 million. Integrated circuits accounted for only a slightly larger share of total exports over the 1967 to 1973 period. Exports of transistors and other semiconductor products such as diodes and rectifiers remained relatively constant in terms of the absolute amount exported but declined in their relative share of total exports.

Table 6-6 shows the geographic distribution of U.S. exports of transistors, integrated circuits, and semiconductor parts.

Over 91 percent of U.S. exports are shipped to the EEC and nine other countries (Japan, Canada, Switzerland, Mexico, Singapore, Korea, Hong Kong, Malaysia, and Taiwan). In 1973 six underdeveloped countries imported almost 70 percent of U.S. exports of transistors, integrated circuits, and semiconductor parts. The large share of U.S. exports going to these countries was the result of the establishment of offshore assembly plants. The relative share of total U.S. exports shipped to developed countries fell from 70 percent in 1967 to nearly 30 percent by 1973. The brief increase in exports to Japan in 1970 was caused by a special set of circumstances. The Japanese had originally dominated the electronic calculator market. An advance in the technology

Table 6-4

U.S. International Trade in Semiconductor Device 1965-73

	1965	1966	1967	1968	1969	1970	1971	1972	1973
Exports[1] ($M)	82	130	152	204	346	417	371	470	848
Imports[1] ($M)	24	42	50	87	104	157	179	330	619
Trade Balance ($M)	+58	+88	+102	+117	+242	+260	+192	+140	+229
Total U.S. Sales[3] ($M)	1122	1467	1385	1415	1687	1720	1593	1848	2400[4]
Trade Balance as a % of U.S. Sales	5.1	6.0	7.4	8.3	14.5	15.3	12.0	7.5	9.5[4]

[1] Exports include subassembly destined for assembly and reimportation under Tariff Items 806.30 and 807.00.

[2] Imports include devices originating from the U.S. and assembled abroad for reimportation.

[3] Domestic sales plus exports (net of 806-807 trade).

[4] Estimated.

Sources: Anthony M. Golding, "The Semiconductor Industry in Britain and the United States: A Case Study in Innovation, Growth, and the Diffusion of Technology", p. 138; Electronic Industries Yearbook 1973, Table 98, p. 101; 1973, U.S. Department of Commerce, memo, "U.S. Trade Deficit in Communication and Selected Electronic Products", July 1974; factory sales data, U.S. Department of Commerce, unpublished data.

Table 6-5

Distribution by Product Type of U.S. Exports of Transistors, Integrated Circuits, Parts of Semiconductors, and Other Devices: 1967-1973

(Percent Distribution)

	1967	1968	1969	1970	1971	1972	1973
Transistors	30.4	25.0	24.0	21.2	13.6	13.0	11.2
Integrated Circuits	17.5	17.8	20.9	23.8	24.6	22.0	25.1
Parts of Semi-conductors	27.5	37.8	38.4	40.0	47.1	50.2	49.7
Other	24.6	19.4	16.7	15.0	14.7	14.8	14.0
Total	100	100	100	100	100	100	100
Total Exports ($ Million)	152	204	346	420	371	470	848

Source: U.S. Department of Commerce, U.S. International Trade of Communication and Selected Electronic Products for Calendar Years 1967-1972 (Washington, D.C.: Government Printing Office, 1973); 1973, U.S. Department of Commerce, memo, "U.S. Trade Deficit in Communication and Selected Electronic Products," July 1974.

Table 6-6

Geographical Distribution of U.S. Exports

of Transistors, Integrated Circuits, and Semiconductor Parts, 1967-73

(Percent Distribution)

<table>
<tr><th></th><th>1967</th><th>1968</th><th>1969</th><th>1970</th><th>1971</th><th>1972</th><th>1973</th></tr>
<tr><td>EEC[1]</td><td>26.4</td><td>22.0</td><td>23.4</td><td>20.4</td><td>17.7</td><td>18.7</td><td>17.5</td></tr>
<tr><td>United Kingdom</td><td>12.0</td><td>10.0</td><td>8.5</td><td>6.3</td><td>4.0</td><td>4.4</td><td>5.0</td></tr>
<tr><td>Canada</td><td>6.8</td><td>5.5</td><td>3.4</td><td>3.4</td><td>3.6</td><td>4.5</td><td>4.6</td></tr>
<tr><td>Japan</td><td>10.9</td><td>10.8</td><td>11.7</td><td>20.4</td><td>18.9</td><td>10.8</td><td>12.1</td></tr>
<tr><td>Switzerland</td><td>12.5</td><td>7.6</td><td>7.0</td><td>6.0</td><td>4.2</td><td>4.2</td><td>NR[2]</td></tr>
<tr><td>Mexico</td><td>4.9</td><td>12.0</td><td>10.0</td><td>12.0</td><td>14.3</td><td>11.2</td><td>8.3</td></tr>
<tr><td>Singapore</td><td rowspan="4">25.7</td><td rowspan="4">31.0</td><td rowspan="4">34.8</td><td rowspan="4">30.5</td><td>9.0</td><td>16.0</td><td>16.5</td></tr>
<tr><td>Korea</td><td>9.6</td><td>9.7</td><td>10.3</td></tr>
<tr><td>Hong Kong</td><td>7.8</td><td>9.3</td><td>7.1</td></tr>
<tr><td>Other[3]</td><td>10.8</td><td>11.3</td><td>18.6</td></tr>
<tr><td>Total[4]</td><td>100.0</td><td>100.0</td><td>100.0</td><td>100.0</td><td>100.0</td><td>100.0</td><td>100.0</td></tr>
<tr><td>Total[5] ($ Million)</td><td>114.7</td><td>164.4</td><td>287.8</td><td>356.4</td><td>316.5</td><td>401.0</td><td>737.9</td></tr>
</table>

[1] Excluding United Kingdom, Ireland and Denmark.

[2] Not reported.

[3] Includes Singapore, Korea and Hong Kong, 1967-1970.

[4] May not add to 100 percent due to rounding

[5] Exports of transistors, integrated circuits, and semiconductor parts only.

Source: Same as Table 6-5.

relating to the integrated circuits used in calculators was made by a U.S. firm; this lead to the deterioration of the Japanese dominance of the calculator market. The Japanese were temporarily forced to import large quantities of the newer calculator devices until their domestic producers imitated the newer technology.

U.S. imports of semiconductor devices have also grown rapidly. (See Table 6-4.) A major factor in the increase of U.S. imports is the reimportation of devices shipped offshore for assembly. Nearly 90 percent of U.S. imports originate from six countries which have the bulk of the offshore facilities. (See Table 6-7.) The composition of imports has also changed over the past five years. Integrated circuit imports have grown substantially and by 1973 accounted for well over half of total imports. (See Table 6-8.)

While the level of both exports and imports was increasing, net exports have fluctuated around $200 million since 1969; in 1973 they were $227 million. From 1965 to 1970 the trade surplus relative to the level of factory sales increased steadily. But recently it has declined sharply. The reasons for the decline will be discussed in the next chapter.

Table 6-7

Geographical Distribution of U.S. Semiconductor Imports

by Origin, 1967-1973

(Percent Distribution)

	1967	1968	1969	1970	1971	1972	1973
EEC[1]	10.8	8.5	4.8	2.9	2.8	3.4	3.7
United Kingdom	1.6	1.6	0.6	1.4	5.5	1.0	0.7
Canada	6.4	4.6	7.6	1.1	1.1	2.1	1.6
Japan	13.8	8.0	1.3	4.6	3.9	5.4	6.1
Mexico					21.1	16.5	14.1
Singapore					22.8	24.5	23.6
Korea					7.4	14.5	13.7
Hong Kong	67.4	77.3	85.7	90.0	17.8	14.2	12.3
Taiwan					7.9	7.7	9.6
Ireland					3.2	5.6	4.0
Other[2]					6.5	5.1	10.6
	100	100	100	100	100	100	100
Total Imports ($ Million)	50	87	104	157	179	330	619

Note: The 1967–1970 values (67.4, 77.3, 85.7, 90.0) are bracketed to cover Mexico through Other combined.

[1] Excluding U.K., Ireland, and Denmark.

[2] Includes Mexico, Singapore, Korea, Hong Kong, Taiwan and Ireland, 1967-1970.

Source: Same as Table 6-5.

Table 6-8

Distribution by Product Type of U.S. Imports of
Transistors, Integrated Circuits, and Other Devices: 1967-1973

(Percent)

	1967	1968	1969	1970	1971	1972	1973
Transistors	62.0	62.3	56.7	38.4	33.7	30.4	25.9
Integrated circuits	----	----	----	44.2	52.6	54.5	58.1
Other	38.0	37.7	43.3	17.4	13.7	15.1	16.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total Imports ($ Million)	50	87	104	157	179	330	619

Source: Same as Table 6-5.

Chapter 7

The Use of Alternative Channels of Technology Transfer by U.S. Based Firms and Their Impact on Trade

Introduction

The three preceding chapters discussed the different channels used to transfer semiconductor technology. This chapter will examine two important related issues concerning technology transfer. First, what are the characteristics of the firms transferring U.S. semiconductor technology abroad and do these characteristics vary according to the type of transfer channel? This issue has been touched upon, at least inferentially, in earlier chapters; here we draw upon the foregoing materials to bear more directly on this important issue. The channels considered will be licensing and direct foreign investment.

The second issue is whether direct investment in production facilities substitutes for U.S. exports or is complementary to U.S. exports.

It should be noted that the different channels of technology transfer which have been detailed thus far are really of two types. One type transfers technical know-how to unaffiliated foreign firms. The second type of transfer is between a U.S. parent and its foreign affiliates. We have not distinguished between the two types. The description of licensing transfers was based on the first definition of technology transfer while a transfer via direct foreign investment was assumed to be of the latter type. This distinction has not been clearly made since it is not critical to the objective of this paper which is to detail the use of alternative channels and the characteristics of firms using the different modes of transfer. We mention this point now to alert the reader to this limitation of the following discussion.

7.a Licensing and Direct Foreign Investment

Of the two basic types of licenses issued by semiconductor firms, only a license which includes technical assistance can really be considered a transfer of new know-how to the licensee. A patent license merely confers the legal privilege to use a specific patent of the licensor. (Firms applying for a patent license have usually mastered the technical process covered by the patent and are only seeking to protect themselves from legal complications.) One further distinction concerning types of know-how licenses should also be made. A second source transfer only covers product related know-how and grants only limited access to the licensor's technology. Technical assistance agreements covering process know-how, for reasons explained in Chapter 4, can be of some importance to the foreign recipient because they expand his production capability.

The sale of process know-how via technical assistance agreements was dominated by the larger firms in the industry. (Large in this context refers to the entire corporation not just the semiconductor division. See the footnote to Table 2-1.) Out of a sample of 42 U.S. firms, 13 had transferred know-how to a foreign firm. Nine of the 13 firms were large. Furthermore, only the large firms engaged in frequent sales of process know-how.

The smaller semiconductor firms have usually not utilized technical assistance arrangements. This finding runs contrary to the widely held belief that licensing would be a more commonly used channel by relatively smaller firms. The small semiconductor firms interviewed for this study generally felt licensing was unprofitable because high marginal costs were incurred in supporting know-how agreements which exceeded potential license income. The high marginal costs were due to the substantial opportunity cost of using scarce engineering talent to assist a foreign licensee. Several firms did note, though, that they temporarily engaged in know-how licensing during the 1970-71 recession in the U.S. semiconductor market. They were reluctant to release excess engineers; hence, during this period the opportunity cost was essentially zero.

Large firms, on the other hand, already have engineering staffs available to support a license agreement. They have found licenses profitable since opportunity costs are quite low. Some large firms, deemphasizing production for the open market, have continued to capitalize on their earlier research efforts by licensing foreign firms. Westinghouse's semiconductor division, for example, derived a major portion of its revenue in 1972 from licenses.

In general, there seem to be four dominant factors which influence the decision to engage in technical assistance licensing. These factors are the size of the firm (total corporate size), its rate of growth relative to the overall industry, its number of patents and their relative importance , and general economic conditions in the U.S. market. We would expect a firm's "propensity to license" to be related in a positive way to the firm size, negatively related to the rate of growth of the firm relative to the total industry growth rate, positively related to the cumulative number of patents of the firm (note this term is positively correlated with firm size, see Table 7-2), and negatively related with general U.S. economic conditions.

The other form of technical assistance transfer, second source agreements, was favored by the smaller firms in the industry. While no information was available on the number of firms engaging in second sourcing agreements with foreign firms, undoubtedly the number is larger than the relatively small number which transfer production know-how. On balance then, all types of semiconductor companies engage in licensing, but only the larger firms tend to agree to contract for technical assistance transfers.

The larger firms have dominated the transfer of technology abroad via direct foreign investment. (See Table 7-1.) Nearly 75 percent of foreign manufacturing operations were established by the larger industry members. The 10 conglomerates in the sample (especially Texas Instruments, ITT, General Instruments, and Motorola) had set up 43 foreign affiliates, 14 of which had received wafer fabrication capability. The large, successful spin-offs (National and Signetics), though having formed 22 foreign affiliates, had only twice transferred wafer fabrication. The smaller semiconductor firms had not established a single wafer fabrication facility abroad. Small firms pursuing a second source or specialty device strategy established fewer offshore facilities per firm than any other type of firm. These firms were among the smallest in the sample and required on average only one offshore facility to remain competitive in the U.S. market. The small innovating firms, the technological leaders of the industry, did not establish any POS facilities. There are two reasons for this. First, foreign demand could be adequately satisfied through exports from the U.S. because they usually had a temporary monopoly position in a new market. They did not immediately face direct competition with the larger firms (either domestic or foreign). Second, the innovating firm's financial resources were limited; during its initial period of expansion it concentrated its resources on the American market. To survive in the domestic market over the long term required an adequate offshore assembly capability, so this was the initial type of foreign facility established.

Considering all channels of technology transfer, the larger firms in the semiconductor industry tend to be more actively transferring technology abroad. This conclusion is mainly based on the greater willingness of these larger firms to engage in know-how licensing and the relative number of affiliates of these firms which have received wafer fabrication technology.

Table 7-1

U.S. Foreign Affiliates by Type of U.S. Parent Firm

	Number of Parent firms	Number of Foreign Affiliates[2]		
		POS	Wafer fabrication	Offshore
Large Companies[1]				
Conglomerates	10	13	14	16
Spin-offs	4	8	2	12
Receiving-tube	3	3	1	5
Total	17	24	17	33
Small Companies				
Second source/ Specialty	12	4	0	10
Innovator	4	0	0	4
Total	15	4	0	14
Total	32	28	17	47

[1]See Table 2-1 for definition.

[2]Excluding subcontractor operations.

Source: See Table 5-1.

Are the larger firms also the most technologically oriented in the industry? Table 7-2 shows the Kendall correlation coefficients between measures of firm size, foreign activity, and technological capability. (The sample of 33 firms from which this data was obtained overlaps but is not identical with the sample used in Chapter 5.) Total semiconductor sales are significantly correlated with R&D expenditures and with the annual average of number of patents. Measured by these absolute standards, the larger firms are more technologically oriented.

However, relative to their size, the larger firms in the industry do not appear to be more technologically intensive. R&D as a share of total U.S. sales (or total company sales) is negatively related to total U.S. company sales (and total sales). This type of measure is subject to criticism since not all firms measure R&D expenditures in the same way (for example, some firms include marketing expenditures) and second, the measure obscures whether the firm is attempting merely to duplicate competitor innovations or advance into new technical areas. Despite these types of criticisms the results are in agreement with the general industry belief that the larger firms are not the technological leaders in the industry. (This excludes peripheral firms such as IBM and AT&T from consideration. See Section 2.b.)

The important implication is that one type of firm -- the small spin-off companies -- has been primarily responsible for the development of new technology and its diffusion in the U.S. while another -- the large multi-divisional firm -- has been primarily responsible for the international diffusion of semiconductor technology.

Table 7-2

Kendall Correlation Coefficients: 1972 Cross-section of 33 U.S. Semiconductor Companies[1]

	Total Sales ($) (1)	U.S. Sales ($) (2)	Foreign Sales ($) (3)	Foreign Sales (%) (4)	POS Affl (5)	R&D ($) (6)	Patents (7)	R&D/ U.S. Sales (8)	R&D/ Total Sales (9)
1. Total Sales ($)	---								
2. U.S. Sales ($)	0.90** (33)	---							
3. Foreign Sales ($) (Exports & For. Production)	0.78** (26)	0.70** (26)	---						
4. Foreign Sales (% total company sales)	0.55** (33)	0.80** (26)	0.38** (26)	---					
5. Number of POS affiliates	0.67** (15)	0.60** (15)	0.65** (12)	0.32 (12)	---				
6. Company R&D ($)	0.06 (24)	0.09 (24)	-0.03 (20)	0.11 (20)	0.20 (12)	---			
7. Average Annual Patents	0.52** (30)	0.67** (33)	0.55** (26)	-0.14 (26)	0.37** (33)	0.04 (24)	---		
8. R&D/U.S. Sales (%)	-0.73** (24)	-0.87** (24)	-0.61** (24)	-0.18 (20)	-0.51** (24)	0.19 (24)	-0.61** (24)	---	
9. R&D/Total Sales (%)	-0.75** (24)	-0.84** (24)	-0.75** (20)	-0.32* (20)	-0.50** (24)	0.19 (24)	-0.53** (24)	0.84** (24)	---

Number of cases in parenthesis below correlation coefficient.

*Significant at 0.05 level.

**Significant at 0.01 level.

[1]Excludes AT&T and IBM.

Source: See Appendix A.

7.b The Effect of Offshore Facilities on Semiconductor Trade

This section will discuss the effect of investment in offshore assembly operations on U.S. exports and the U.S. balance of trade in semiconductors. The next section will relate investment in developed countries to U.S. export patterns.

Investment in offshore facilities which assemble parts for reexport back to the U.S. has had a positive effect on U.S. exports. Equation 7.1 estimates the relationship between exports of semiconductor parts to a country (X_c) in millions of dollars and the number of offshore assembly affiliates of U.S. companies located in that country (N_c). The relationship was estimated for 14 countries using 1972 trade data.

$$(7.1) \qquad X_c = 1.99 + \underset{(6.66)}{4.33}\, N_c$$

$$\bar{R}^2 = 0.75 \qquad N = 14$$

The positive relationship is certainly no surprise; it should be noted that the positive relationship is not attributable to a common dependence of both exports and the number of offshore affiliates upon market size. In many of the countries in the cross-section sample, prior to the establishment of U.S. facilities, no domestic semiconductor industry existed (nor would there have been an indigenous demand for semiconductors). The export of semiconductor parts has become the largest segment of U.S. exports with developing countries the major region where these parts are shipped.

To understand the impact which offshore assembly has had on the U.S. semiconductor trade balance, it is necessary to examine the trade flows in greater detail. The total value of U.S. semiconductor exports can be divided into two components: (1) export of sub-assemblies which are returned as assembled devices to the U.S.; (2) exports destined for foreign consumption. Imports can be divided into three components: (1) the U.S. content of reimported devices; (2) the value added by foreign assembly to U.S. parts reexported to the U.S.; (3) imports from foreign producers. United States trade data for semiconductor exports and imports, compiled on a geographic basis, include shipments between wafer fabrication facilities in the U.S. and offshore assembly plants which are subsequently reexported back to the U.S. If these transfers were excluded from the trade accounts, the trade figures would only reflect exports to foreign consumers and imports from foreign controlled plants. This will be referred to as the trade surplus computed on ownership basis. The advantage of measuring trade flows in this way is that the resulting net trade balance will serve as a better measure of the competitive advantage of U.S. firms and the U.S. industry than it would if measured on the traditional geographic basis which measures the advantage of the U.S. as a production location.

The examination of actual U.S. trade data will begin with the import side since this will simplify the presentation. Table 7-3 shows the composition of U.S. imports for 1970 to 1973. The U.S. content of imports refers to the value of imports claimed by U.S. firms in customs disclosures to have originated from the U.S. The value added by offshore assembly relative to the U.S. content of imports shows a steady growth. (Line 6 of Table 7-3 shows the ratio of U.S. content to the total value of imports entering under Tariff Items 806-807. U.S. firms have been accused by the U.S. Bureau of Customs of deliberately understating the value added by offshore assembly.' Bias resulting from undervaluation would tend to decrease the growth of value added by offshore plants relative to the value of total imports. But line 6 of Table 7-3 shows a consistent downtrend in the content of imports originating in the U.S. Any reporting error in the value added data would

Table 7-3

Composition of U.S. Semiconductor Imports, 1970-1973

($ Million)

	1970	1971	1972	1973
1. U.S. Content of Total Imports[1]	78.4	81.3	127.3	183.6
2. Value Added by U.S. Offshore Assembly to U.S. Parts	60.2	71.0	122.4	224.8
3. Imports from Developed Countries (Non-U.S. owned facilities)	12.9	24.5	39.6	61.6
4. Imports Originating from LDC's (Non-U.S. owned facilities)	5.0	2.3	41.0	148.6
5. Total U.S. Semiconductor Imports	156.5	179.1	330.3	618.6
6. Ratio: U.S. Content of Imports to Total Offshore Imports (1 ÷ (2 + 1)).	57%	53%	52%	45%

[1]Value of U.S. content is the value of U.S. manufactured parts exported for offshore assembly and reimported back to the U.S.; calculated by U.S. Bureau of the Census from customs filings of U.S. semiconductor companies.

Source: U.S. Department of Commerce, unpublished data.

not change the basic conclusion regarding the growing importance of offshore activities.

Imports originating in developed countries show little increase relative to the total size of U.S. imports. Imports originating from LDC's (Line 4, Table 7-3) show an explosive rate of growth increasing from $5 million in 1970 to nearly $150 million by 1973. While the reasons for this sudden increase are not well known, two factors seem to have been important. First the large increase in domestic demand in 1973 exceeded the U.S. industry's capacity. (The recession of 19[illegible] slowed the industry's expansion.) Second, semiconductor demand grew fastest in the consumer products markets where foreign producers had their greatest production experience. The major source of these imports are the affiliates of semiconductor firms of other developed countries, particularly Japan. Whether there is any sizeable indigenous LDC production cannot be determined from the data.

Table 7-4 shows the composition of U.S. exports between 1970 and 1973. U.S. exports to developed countries (line 2) will be discussed in the next section. The total export of parts to LDCs for assembly (line 1) has grown relative to total exports. Within this category exports destined for reimport have accounted for between 50 and 60 percent. Assembled parts which are not returned to the U.S. are either embodied in electronic systems (which possibly are exported to the U.S.) or are shipped to a third country. The transshipment of assembled devices to a third country from an offshore or POS plant will be referred to as indirect export in subsequent sections.

We can now return to the question of the influence of offshore production on the U.S. balance of trade in semiconductors. Since the U.S. content of imports will be netted out when computing the trade balance, only the value added by offshore assembly to materials destined for the U.S. will affect the U.S. trade balance.

Table 7-4

Composition of U.S. Semiconductor Exports, 1970-1973

($ Million)

	1970	1971	1972	1973
1. Total U.S. Exports of Semiconductor Parts to LDCs	134.6	138.6	205.6	365.8
1a. U.S. Exports of Semiconductor Parts Ultimately Reimported by the U.S.[1]	78.4	81.3	127.3	183.6
1b. U.S. Exports of Semiconductor Parts to LDCs (Line 1 - line 1a)	56.2	57.3	78.3	82.2
2. U.S. Exports to Developed Countries[2]	249.2	215.6	233.4	423.6
3. All Other Exports	33.2	16.3	30.6	59.1
4. Total Exports	417.0	370.5	469.6	848.5
5. Total U.S. Exports Destined for Foreign Markets (1b + 2 + 3).	338.6	289.2	342.3	664.9
6. Ratio: Exports Destined for Re-import to Total Exports of Parts to LDCs (1a ÷ 1).	59%	59%	61%	50%

[1]See Table 7-3, footnote 1.

[2]EEC (including Britain), Canada and Japan.

Source: Same as Table 6-4.

To compute the trade balance on an ownership basis, the value added by foreign assembly must be added to the value of the trade surplus computed on a geographic basis. (See Table 7-5.) The trade balance computed on an ownership basis does not show the same pattern over the 1970-1973 period that the geographic trade balance exhibits. The relative level of the trade balance reflected in the two measures is diverging. By 1973 the trade surplus measured on an ownership basis reached a level nearly double that of the trade surplus measured on a geographic basis.

It should be noted that in the preceding discussion the notion of comparative advantage was not used in its more common form. Typically comparative advantage is defined with regard to geographic entities. But here we are referring to the comparative advantage of U.S. firms in the U.S. market relative to foreign competitors. The measure being proposed reflects the relative competitive strength of U.S. versus foreign firms regardless of the geographic location of the factors of production.

In conclusion, the presence of offshore facilities tends to raise the absolute level of U.S. exports and imports but depress the official trade balance (calculated on the traditional geographic basis) relative to what it would be if it only reflected trade with non-U.S. firms (that is, calculated on an ownership basis). These effects are due to the fact that U.S. owned foreign production plants are the source of imports into the U.S.

7.c Relationship of Semiconductor Trade and Direct Foreign Investment in Developed Countries

Direct foreign investment in POS plants in developed countries impacts on U.S. semiconductor trade differently from offshore assembly operations. The offshore plants affected both U.S. exports and imports. Point-of-sale assembly and wafer fabrication affect only the level and distribution of U.S. exports.

Table 7-5

U.S. Semiconductor Trade Balance: Ownership vs. Geographic Basis

($ Million)

	1970	1971	1972	1973
1. Total U.S. Exports	417.0	370.5	469.5	848.5
1a. Total U.S. Exports, Net of U.S. Content[1] (Line 5, Table 7-4).	338.6	289.2	342.3	664.9
1b. Total U.S. Content (Line 1 - Line 1a) of Exports. (See Line 1a, Table 7-4).	78.4	81.3	127.3	183.6
2. Total U.S. Imports Originating from Non-U.S. Owned Sources (Line 3 + Line 4, Table 7-3).	17.9	26.8	80.6	210.2
3. U.S. Trade Balance, Ownership Basis (Line 1a - Line 2).	319.7	262.4	261.7	454.7
4. U.S. Trade Balance, Geographic Basis	260	192	140	229

[1] U.S. content refers to the share of U.S. exports assembled offshore subsequently reimported. See Table 7-3, footnote 1.

Source: Same as Table 6-4.

(Ignoring any transfers of technology to host country by semiconductor firms which could stimulate exports to the U.S.) In this section direct U.S. exports will be defined as the total exports of semiconductors net of parts exports to developing countries. Deducting parts exports to LDC's attempts to eliminate the 807-806 portion of U.S. exports and the indirect exports to developed countries. (Indirect export was defined in Section 7.b.)

Direct U.S. exports of semiconductors increased consistently from 1965 to 1969 both in absolute terms and as a percentage of foreign consumption of semiconductors in major foreign markets. (See Tables 7-6, 7-7. Major foreign market consumption is defined as the annual consumption of semiconductors in Japan, Britain, Germany, and France; in 1972, these four countries consumed 75 percent of the free world semiconductor production excluding the United States.[1]) Between 1969 and 1973, the growth of direct exports slowed. Direct U.S. exports as a percentage of foreign consumption showed a marked decline over this period. Part of this decline was due to the reduction in integrated circuits exports to Japan (see Section 6.c). But the U.S. export share in other developed countries, particularly Britain and Germany, also declined. (See Table 7-8.)

The direct export of semiconductor parts to developed countries (the EEC, Canada, and Japan) showed consistent gains from 1965 on except for a small decline in 1972. (See Table 7-6, column 3). It is interesting to compare the growth of POS affiliates in developed countries (including wafer fabrication facilities) with the trend of parts exports. The number of POS facilities increased fairly slowly until the 1969-1971 period when the cumulative number more than doubled. (See Table 7-7, column 3). There was no major redistribution of exports between parts and finished devices corresponding to the increased number of POS affiliates. The only major change after the 1969 period was the sharp decline in the U.S. export share of the major foreign markets. (See Table 7-7, column 2.)

Table 7-6

U.S. Exports to Developed Countries[1], 1965-1973

	(1) Total U.S. Exports ($ Million)	(2) Exports to Developed Countries[2] ($ Million)	(3) Parts Exports to Developed Countries ($ Million)	(4) Developed Country Share of Total Exports (2 ÷ 1) (Percent)	(5) Parts Exports as % of Exports to Dev. Countries (3 ÷ 2) (Percent)
1965	82.0	74.7	8.4	91	11.2
1966	130.0	93.7	10.0	72	10.4
1967	152.0	124.4	14.4	82	11.6
1968	204.5	146.0	18.1	72	12.4
1969	346.2	244.1	30.7	71	12.6
1970	417.0	249.2	33.0	59	13.3
1971	370.5	215.6	36.3	58	16.8
1972	470.5	233.4	30.5	50	13.1
1973	848.5	423.6	59.0	50	14.0

[1] EEC (including Britain), Canada and Japan.
[2] Including parts, column 3.

Source: See Table 6-5.

Table 7-7

Foreign Semiconductor Consumption[1] and Percentage Supplied by U.S. Exports, 1960-1972

	(1) Major Foreign Market Consumption of Semiconductors[3] ($ Million)	(2) U.S. Export Share[2] of Major Foreign Market Consumption[3] (Percent)	(3) Cumulative U.S. POS Affiliates Dev. Countries[3] (Number of Affl.)
1960	134	11	5
1961	151	15	6
1962	174	16	6
1963	208	17	7
1964	248	16	8
1965	323	23	8
1966	349	27	10
1967	390	32	11
1968	490	30	13
1969	660	37	24
1970	840	30	29
1971	875	25	30
1972	1284	18	34

[1]Consumption in Japan, Britain, Germany, France.

[2]Export share calculated from column 2, Table 7-6 ÷ Column 1, Table 7-7.

[3]Japan, Britain, Germany, France.

Source: Consumption figures estimated by author; foreign facilities data from Tables 5-1, 2, 3.

Table 7-8

U.S. Export Share of Major Foreign Market Consumption, 1967-1972

(Percent)

	Japan	Britain	Germany	France
1967	11	20	21	16
1968	10	23	32	19
1969	13	24	30	26
1970	19	18	28	24
1971	15	11	21	18
1972	6	14	18	29

Source: See Tables 7-7, 6-5.

Two fundamental changes occurred over the 1969-1971 period in the way U.S. semiconductor companies served developed country markets. While direct exports accounted for approximately 66 percent of the U.S. share of the developed country markets in 1968, that share declined to 40 percent by 1972. (See Tables 7-9 and 7-10.) The first change in the way major foreign markets were supplied was the large increase in indirect imports from American POS and offshore facilities located in LDC's. (See Table 7-11.) The estimated value of U.S. indirect exports to developed countries is very rough. The share of the developed country market supplied via indirect exports grew from an estimated 7 percent in 1968 to 20 percent in 1972. The second major change was the development of a substantial wafer production capacity in Europe. Host country production including wafer fabrication by American firms grew from an estimated $36 million in 1968 to an estimated $174 million by 1972. (These figures exclude the value added by assembly to direct exports of parts. Including this value would increase the 1968 estimate of $36 million to $49 million and the 1972 estimate of $174 million to $207 million. The change from 1968 to 1972 would then be $158 million compared to $138 million if value added by assembly to diredt parts exports were included.)

Semiconductor trade flows have also been influenced by shipments between American POS affiliates which redistribute American exports among final consuming countries. While this trans-shipment between American affiliates may be substantial, it cannot be fully measured. However, there is one good example of this activity in the case of American exports to Switzerland, where adequate information exists on the extent of trans-shipment or pass-through of American exports.

U.S. Commerce Department data show U.S. semiconductor exports to Switzerland

Table 7-9

U.S. Companies' Market Share in 4 Major Consuming Countries[1], 1968/1972

		1968	1972
1.	Percent share in individual countries		
	United Kingdom	53.0	58.6
	Germany	36.0	51.4
	France	33.0	95.0
	Japan	10.0	12.4
2.	Arithmetic Average (%)	33.0	54.3
3.	Consumption Weighted Average (%)	27.8	34.0
4.	Estimated consumption in all 4 countries ($ Mil)	$490	$1284
5.	U.S. Share Foreign Consumption, Line 3 x Line 4 ($ Mil)	$137	$437

[1]Japan, Britain, Germany, France.

Source: 1968: John Tilton, ibid, p. 110; 1972: U.S. Department of Commerce, unpublished data.

Table 7-10

Composition of U.S. Companies' Share of 4 Major Consuming Countries[1], 1968/1972
($ Million)

	1968	1972
1. Total Direct Exports plus Value Added	$91	$184
1a. Finished Devices	$65	$129
1b. Parts	$13	$22
1c. Value Added to Direct Export Parts in Consuming Countries by U.S.-owned Affiliates[2]	$13	$33
2. Indirect Exports[3]	$10	$79
3. Residual: U.S. Wafer Fabrication and Assembly in Host Countries[4]	$36	$174
4. Total U.S. Share Foreign Consumption Line 1 + Line 2 + Line 3	$137	$437

[1]Japan, Britain, Germany, France.

[2]Estimated; excludes Japan for 1968.

[3]1968 estimated; 1972 value estimated to be 50% of sum of columns 3 and 4 Table 7-11.

[4]Value added in assembly to indirect exports and to wafers produced in host countries plus value of wafer fabrication; (Line 1 + Line 2) minus Line 4.

Source: Same as Table 7-9.

Table 7-11

Estimated Direct and Indirect U.S. Exports to Developed Countries, 1970-1973

	(1) Estimated foreign consumption of semiconductors[1] ($ Million)	(2) Direct U.S. exports to developed countries[2] ($Million)	(3) Estimated indirect exports to developed countries[3]: U.S. Content ($ million)	(4) Estimated indirect exports to developed countries[3]: Estimated Value-added in Host Countries ($ million)	(5) Estimated total direct & in-direct exports ($ Million) (2+3+4)	(6) Indirect share exports (Percent) ((3+4) ÷ 5)	(7) Total exports as share of for. consumption (Percent) (5 ÷ 1)
1968	490	146.0	10		156.0	6	32
1969	660	244.1	20		264.1	8	40
1970	840	249.2	28.3	21.4	298.9	17	36
1971	875	215.6	28.7	25.2	269.5	20	31
1972	1284	233.4	39.6	39.0	312.0	25	24
1973	2400[4]	423.6	91.1	112.0	626.7	32	26[4]

[1] Britain, France, Germany, Japan.

[2] Exports shipped directly to the EEC (including Britain), Canada and Japan.

[3] Exports from U.S. offshore affiliates to Britain, France, Germany, Japan; U.S. content estimated to be 50% of Line 1b, Table 7-5 ; value added factored at same rate as value added to U.S. imports from U.S. offshore plants.

[4] Estimated.

Source: Same as Table 6-4.

exceeding $12 million between 1969 and 1972. (See Table 7-12.) But only half of these exports were actually consumed within Switzerland. U.S. firms re-exported the balance primarily to the United Kingdom and France. Motorola's European distribution center located in Switzerland was a major source of the pass-through.

Recent changes to EEC and EFTA agreements make this type of transfer less advantageous. Formerly, U.S. companies could export to a third country via Switzerland and only pay a nominal duty on the total transaction. Now full EEC duty is assessed against products shipped from one European trade group to another if 41 percent of the product's value was added outside the EEC or EFTA.

While the increased use of offshore assembly plants led to an increased export of semi-finished devices to low wage areas, the more interesting question concerning trade and investment pertains to POS plants and trade with developed countries. Unlike the case of offshore plants, the evidence does not conclusively support either complementarity or substitution between U.S. exports and U.S. foreign direct investment.

Semiconductor firms interviewed for this study generally argued that their direct foreign investment activities had a favorable impact on exports. The reasons given were of three general types. First, direct and indirect exports can be passed-through a POS affiliate in the host country market without the host country feeling the U.S. firm is acting solely as an importer. Several firms cited the difficulty of importing into France without operating a manufacturing plant there. The ability to import devices from assembly plants in low wage areas was seen as an especially necessary capability since it allowed the American firm to be very price competitive (and usually a price leader) in the host country market. Second, customer support supplied by an affiliate

Table 7-12

U.S. Exports Passed-Through Switzerland 1969-1972

	Year	U.S. Exports to Switzerland ($ Thousand)	U.S. Exports Consumed in Switzerland ($ Thousand)	Net Passed-Through ($ Thousand)
A.	Integrated Circuits			
	1969	7969	740	7529
	1971	7948	1100	6848
	1972	7116	2000	5116
B.	Transistors			
	1969	11771	2800	8971
	1971	13138	3900	9238
	1972	5429	4600	829

Sources: U.S. Department of Commerce, Country Market Survey: Switzerland, November 1973; U.S. International Trade of Communication and Selected Electronic Products for Calendar Years 1967-72.

makes the host country consumers more willing to standardize on a foreign originated device. (The support includes custom design for special applications and quality control for increased reliability.) Third, as discussed in Section 5.b.4, U.S. firms have a greater flexibility in establishing their prices. The ability to decouple European market prices from U.S. market prices enhances the ability of U.S. firms to export directly into Europe.

While it is difficult to totally discount the arguments favorably linking exports and investment, the empirical evidence tends to support a different view. The data suggests that investment in POS plants has substituted foreign production in developed countries for direct U.S. exports of finished devices. While the U.S. companies' share of the major foreign markets increased from 28 percent in 1968 to 34 percent in 1972, the part of this share accounted for by direct and indirect imports declined from 63 percent to 34 percent in 1972 and the part accounted for by direct exports alone declined from 58 percent in 1968 to 30 percent in 1972. This narrower definition would be combining the effects of all forms of foreign direct investment on direct exports of finished devices.

Additional evidence supporting the argument that foreign production substituted fo export comes from examining time series data on U.S. exports, number of U.S. foreign affiliates, and several market activity variables. Equation 7-2 relates the ratio of annual U.S. exports net of parts exports to LDCs (X) to annual British, German, French, and Japanese consumption of semiconductors (CONS) as a function of the European and Japanese industrial production index (IP) and the cumulative number of U.S. POS affiliates in developed countries lagged one period (AFFL(-1)). The form of the relation assumes an elasticity of unity between U.S. exports and developed country semiconductor consumption. The coefficient of the affiliate term is negative and moderately significant. (t-statistic for coefficients in parenthesis. Data on exports and consumption are from Tables 7-6 and 7-7; data on affiliates from Table 5-2.)

$$(7\text{-}2) \qquad \text{Log (X/CONS)} = \underset{(-3.8)}{-10.7} + \underset{(3.03)}{1.94} * \text{Log (IP)} \underset{(1.88)+}{- .52} * \text{Log (AFFL(-1))}$$

$$\bar{R}^2 = 0.67 \qquad DW = 1.56 \qquad \text{Period 1955-1973}$$

Relaxing the assumption of unitary elasticity and adding a relative price term WPIUS/WPIEUR,(the U.S. wholesale price for semiconductors relative to the European wholesale price index) yields results consistent with Equation 7-2 though the coefficient of the affiliates term is not very significant. (Data same as equation 7-2.)

$$(7\text{-}3) \qquad \text{Log (X)} = \underset{(-4.5)}{-2.67} \underset{(1.52)}{-1.32} * \text{Log} \left(\frac{\text{WPIUS}}{\text{WPIEUR}}\right) + \underset{(6.3)}{1.34} * \text{Log (CONS)} \underset{(1.13)}{- .45} * \text{Log (AFFL(-1))}$$

$$\bar{R}^2 = .79 \qquad DW = 1.85 \qquad \text{Period 1955-1973}$$

Finally, using the data collected on U.S. semiconductor company operations for 1972 (see Appendix A), a U.S. company exports as a percentage of domestic sales was related to the existence of foreign affiliates by type. If a firm had any POS affiliates, D1 was set equal to one (and zero otherwise). Similarly D2 equals one whenever a company had any offshore affiliates. (See Equation 7-4.) The results are consistent with the time series results; but an important distinction becomes apparent.

$$(7\text{-}4) \qquad (X/USSales) = \underset{}{0.15} - \underset{(2.63)}{0.19} * D1 + \underset{(1.98)}{0.15} * D2$$

$$\bar{R}^2 = 0.24 \qquad N = 21$$

While the presence of POS affiliates is negatively related to the export share of a company's sales (X/USSales), the opposite relation holds for offshore affiliates.

In summary, the effect of U.S. foreign direct investment on U.S. exports is sensitive to the type of product exported, the type of foreign affiliate, and the location of the foreign affiliate. With regard to U.S. exports of parts to developing countries, the increased number of assembly affiliates in these countries expanded the share of total U.S. exports which flowed to these countries, and, in particular, led to an increased export of semi-finished devices. But the growth of this form of semiconductor exports has not clearly benefited U.S. employment in the industry. (Except if one argues that without going to offshore assembly, U.S. firms could not have remained competitive.)

By establishing POS affiliates, U.S. firms were able to maintain, or in some instances increase, their share of developed country markets. The effect of the growth of POS affiliates on U.S. exports is not completely clear. U.S. export share of major foreign markets has declined. U.S. firms argue that without the presence of a production affiliate within a foreign market, exports would have declined more severely. (Especially in France where nontariff barriers hindered attempts to supply the market solely via exports.) This view, that exports would have fallen whether or not U.S. firms engaged in foreign production, means that the empirically derived negative export-investment relation does not necessarily result from foreign production substituting for exports. But the extent of the fall in the U.S. export share over the 1969-1972 period leads one to believe that some degree of export substitution took place or, conversely, that the export-investment complementarities were not sufficiently significant to prevent a substantial decline in the U.S. export share.

Chapter 8

Summary

American semiconductor manufacturers have dominated the world semiconductor industry since the first commercial application of the transistor in the early 1950's. Previous studies have examined the causes for this dominance and traced the development of the U.S. and foreign industries. (See Tilton and Golding.) This study reviewed the extent and the effects of the outward transfer of semiconductor technology by U.S. firms. Given the dominant role that American firms played in developing the underlying technology for solid state devices, this outward flow of know-how was a particularly important one to study.

Two major factors influenced the transfer of semiconductor technolgoy by American firms: the industry's organization and the characteristics of semiconductor technology. The U.S. semiconductor industry consists of three types of firms: (1) peripheral companies manufacturing semiconductors primarily for internal consumption; (2) large firms with semiconductor operations; (3) small, independent manufacturers. The peripheral firms, primarily Western Electric and IBM, are important because they have large semiconductor R&D programs. The smaller firms act as a stimulus for promoting new innovations within the domestic U.S. industry. But it has been primarily the large firms which have been actively transferring their know-how abroad. The large firms have led in the establishment of a substantial number of foreign affiliates serving foreign markets. Through these affiliates process technology has been directly transferred into foreign countries. These firms (particularly Texas Instruments and Fairchild) have also actively licensed their technology to foreign firms.

Semiconductor production can be segmented into stages of varying degrees of complexity. This ability to segment the production sequence has in turn led to selective transfer of the technology offshore. Each segment can be physically separated from the other with minimal effect on total production costs. The most important stage of production, wafer fabrication, is difficult to transfer due to its complexity.
To date, only affiliates of U.S. firms located in
developed countries have been upgraded to the level of full wafer fabrication. Assembly technology, on the other hand, is simpler and more readily transferred offshore. Additional factors which have affected the selection of semiconductor technology for transfer have been learning economies and economies of scale. Wafer fabrication is subject to substantial learning economies and has tended towards economies of scale. These factors generally encourage firms to concentrate wafer fabrication in a minimum number of facilities. The opposite is the case for assembly.

In choosing between alternative methods of transferring semiconductor technology, the large firms have been constrained by the factors discussed above. The complexity of the process technology makes the sale of it via licenses very difficult to support. Licenses, therefore, have been predominantly only for patent rights. Companies which have sold process know-how have generally limited the sale to older technology with well defined parameters. An additional barrier to licensing process know-how is posed by the learning economies associated with accumulated production volume.

Learning economies cannot be fully transferred by license. The general unwillingness of smaller firms to devote any of their resources to support know-how license arrangements has meant that the large firms are the primary users of this channel to transfer know-how.

Exports have been a major means for U.S. firms to service foreign markets, but this channel has severe limitations in terms of transferring technology. Foreign firms are able to imitate exported devices but this requires them to have already acquired the necessary process know-how. Additionally, if they do imitate the device, they must start down the learning curve lagging the American firms in cost reductions.

Overall, one is left with the impression, despite the rapid growth of foreign operations, that U.S. firms have retained tight control over their production techniques, particularly wafer fabrication. The developed countries have been the sole beneficiaries thus far of transfers of production facilities which include wafer fabrication.

U.S. semiconductor trade flows have been substantially affected by direct foreign investment. Due to the transfer of assembly operations abroad, the absolute size of semiconductor trade has grown rapidly. More importantly, the presence of these plants has allowed the industry to reduce its direct labor expenses and reduce final product costs substantially. This cost reduction has further expanded the potential market for semiconductors in the U.S. and abroad. Due to tariff schedule Items 806-807, U.S. firms using offshore plants gain a cost advantage in the U.S. market over Japanese and European competitors, even if the foreign firms locate their assembly plants in the same developing country. The location of assembly plants in certain countries has enabled American firms to gain access to developed country markets without facing import duties while they retain their low cost labor base. This indirect method of export to developed countries has been expanding.

The share of developed countries' markets serviced by direct semiconductor exports has fallen. Empirical evidence suggests that this decline can be in part attributed to the growth of American POS affiliates in these markets. But other evidence suggests the decline might have been even larger if U.S. firms had failed to establish production affiliates.

Among the different stages of production, American firms have chosen to transfer assembly technology to low wage areas. This phase of production has a significantly lower capital-labor ratio relative to the capital-labor ratio for the entire production process. One important affect of this transfer has been that the occupational distribution of the U.S. industry's domestic labor force has shifted towards more highly skilled occupations.

Appendix A

Data on Sales and Foreign Operations of 36 U.S. Semiconductor Companies

Company	1972					1973				
	Total Sales[1] ($M)	U.S. Sales ($M)	Total Foreign ($M)	Exports[1] ($M)	Foreign Prod'n[2] ($M)	Total Foreign Op'n[4]	Offshore Assembly	POS Assembly	Complete Manuf.	Subcontractor Assembly[r]
Texas Instruments	405	260	145	15	130	15	3	8	4	
Motorola	315	249	66	28	38	8	5	2	1	
Fairchild	172	134	38	10	28	8	5	3		
RCA	81	K	K	K	3	4	3	1		
National	76	58	18	4	14	9	4	4	1	
General Electric	60	U	U	U	U	4	2	2		
Signetics	48	41	7	4	3	4	2	1	1	
General Instruments	36	U	U	U	U	4	2		2	
American Micro-Systems	30	22	8	.8	0	1	1			
Rockwell	25	U	U	U	U	3	2	1		
International Rectifier	23	11[3]	12[5]	U	U	5		3	2	
Intel	21	15	6	6	0	3	1			2
Teledyne	20	U	U	U	U	1	1			
Westinghouse	20	U	U	U	U	1			1	

Transitron	19	U	U	U	U	0	1	1	
Mostek	16	10	6	6	0	3	1		2
TRW	14	K	K	K	K	1		1	
Intersil	13	U	U	U	1	3	2	1	
Advance Memory Systems	13	12	1	1	0	0			
Litronix	12	6	7	U	U	3	2	1	
Siliconix	12	10	2	2	0	2	1	1	
Electronic Arrays	9	6	3	3	0	1	1		
Advanced Micro Devices	9	8	1	1	0	3	1		2
Solitron	8	7	1	U	U	3	2	1	
Semtech	6	U	U	U	U	1		1	
Dickson Electronics	5	4.8	0.2	0.2	0	1	1		
Solid State Scientific	5	4.7	0.3	0.3	0				
Microwave Semiconductor	4.5	3.9	0.6	0.6	0	2			2
Diodes	4	3.5	0.5	0.5	0	1	1		
Monolithic Memories	3	2.3	0.7	0.7	0	4	1		3

Silicon General	2	1.5	0.5	0.5	0				
General Semiconductor	2	1.8	0.2	0.2	0				
Standard Microsystems	1	0.7	0.3	0.3	0	1			1
IT&T						4			
Sprague Electric						3	2	1	
Western Digital						1			1

K- data known but not releaseable

U- data unknown

Appendix A
Notes

[1] Exports are sales made directly to foreign buyers without passing through a foreign affiliate.

[2] Foreign production are sales made to foreign buyers by foreign affiliates of U.S. companies.

[3] Estimated.

Sources: 1972 Form 10-K filed with the U.S. Securities and Exchange Commission; J.P. Ferguson Associates, Los Altos, California; interviews with companies.

APPENDIX B

Two questionaires were used to obtain data for preparation of this paper. The first was used in conjuction with interviews with semiconductor companies. This dealt with licensing policy, transfer of innovations and adaptation of technology. Twenty one companies were interviewed. These interviews provided the main input to Chapters 4 and 5.

The second questionaire was a mail questionaire sent to 40 small semiconductor manufacturers. Firms selected for this survey had less than twenty million dollars in semiconductor sales in 1972 or less than 500 employees. Private rather than public ownership was a second criteria for selection. Many of the smaller companies are privately owned and do not file financial reports with the SEC. Outside of visiting these private firms, a questionaire was the only way to obtain information on their activities.

Thirty one small firms replied to the questionaire; twenty-seven of the responses were used in the final tabulations. The questionaire requested information on initial manufacturing, exporting, license, and foreign manufacture. The data from this questionaire were primarily used in Chapters 4.

APPENDIX C

Location and size of United States offshore Assembly Plants:

COMPANY	YEAR	COUNTRY	EMPLOYEES	SQUARE FOOTAGE	ESTIMATED INVESTMENT ($ Th.)
Advanced Micro Devices	1972	Malaysia	640	20,000	4000
Diodes, Inc.	1972	Mexico	150	12,000	2400
Litronix	1972	Singapore	682	7,500	1500
	1972	Malaysia	1308	15,000	3000
Monolithic Memories	1973	Malaysia	102	15,000	3000
Electronic Arrays	1973	Singapore	743	37,000	7400
National	1974	Singapore	4000	88,000	17600
	1974	Malaysia	2400	30,000	6000
	1972	Hong Kong		10,000	2000
Signetics	1967	Korea	500	30,000	6000
Solitron	1972	Mexico		26,400	5280
	1972	Hong Kong		15,000	3000
Transitron	1972	Mexico	1600	166,000	33200
Fairchild	1967	Hong Kong	6000	145,000	29000
	1967	Korea	1100	18,000	2145
	1974	Singapore	3500	52,000	10400
	1974	Indonesia		80,000	1600
Motorola	1967	Korea	1000	40,000	7500
	1972	Mexico	1000	40,000	8000
	1974	Malaysia	3000	110,000	18000
Mostek	1974	Malaysia	1200	30,000	6000
Harris Semiconductor	1974	Malaysia	2500	40,000	8000
RCA	1974	Malaysia		84,000	

APPENDIX C

(con't)

COMPANY	YEAR	COUNTRY	EMPLOYEES	SQUARE FOOTAGE	ESTIMATED INVESTMENT ($ TH)
Intersil	1969	Singapore		100,000	20000
Carter Semiconductor	1971	Hong Kong	3000	100,000	20000
	1971	Philippines	1000	25,000	5000
General Instrument	1971	Taiwan	900	35,000	7000
Dickson	1972	Mexico	500		
Siliconix	1973	Hong Kong	315	14,000	2800
GE	1973	Ireland	1350		

Source: SEC Form 10-K filings and S-1 filings; Electronic News

FOOTNOTES

INTRODUCTION

[1] Raymond Vernon, "International Investment and International Trade in the Product Cycle," Quarterly Journal of Economics, May 1966, pp. 191-207.

[2] John E. Tilton, International Diffusion of Technology: The Case of Semiconductors (Washington: Brookings Institution, 1971).

[3] Organization for Economic Cooperation and Development, Electronic Components in Technology (Paris: OECD, 1968).

CHAPTER 2

[1] Electronic Market Data Book 1973 (Washington: Electronic Industries Association, 1973), p. 113.

[2] Discussions with industry executives.

[3] For a detailed review of Bell Laboratory's role see Tilton, op. cit., Chapter 4; Anthony M. Golding, "The Semiconductor Industry in Britain and the United States: A Case Study in Innovation, Growth, and the Diffusion of Technology" (Ph.D. dissertation, University of Sussex, 1971), pp. 154-157; Charles Weiner, "How the Transistor Emerged," IEEE Spectrum (January 1973), pp. 24-33.

[4] Weiner, "How the Transistor Emerged," p. 30.

[5] Tilton, op. cit., p. 96.

[6] Golding, op. cit., p. 253.

[7] "TI Story: Consumer and Computers," Electronics (April 12, 1973), p. 83.

[8] Tilton, op. cit., Table 4-8, U.S. Integrated-Circuit Production and Prices, and the Importance of the Defense Market, 1962-1968, p. 91.

[9] For a further discussion of the military's role in the development of the U.S. semiconductor industry see OECD, op. cit., pp. 59-65; Tilton, op. cit., pp. 89-92.

[10] Tilton, op. cit., p. 105.

[11] OECD, op. cit., p. 96.

[12] Tilton, op. cit., p. 96.

CHAPTER 3

[1] Interview with Carlos D. Abrahams, consulting engineer, Carlos D. Abrahams, Associates.

[2] Ibid.

[3] Quote attributed to Dr. Soloman Miller, Quantum Science Corporation, in "Where Time Moves at a Dizzying Pace," Business Week (April 20, 1968), p. 177.

[4] Tilton, op. cit., p. 85.

[5] Tilton, op. cit., pp. 82-84.

[6] Interview with D. Del Frate, Vice President, RCA Semiconductor Division.

[7] Interview with J.P. Ferguson, President, J.P. Ferguson, Associates, Los Altos, California.

[8] George Boardman, "Semiconductor Life Cycles and Profits," Electronic News (September 4, 1972), pp. 34-35.

[9] Dr. Conley, "Experience Curve as a Planning Tool," IEEE Spectrum (June 1970).

[10] Boardman, "Semiconductor Life Cycles and Profits," p. 35.

11 Quote attributed to Dr. Robert N. Noyce, former President of Fairchild, in "Where Time Moves at a Dizzying Pace," Business Week (April 20, 1968), p. 182.

12 Charles W. Beardsley, "The Future of Discretes," IEEE Spectrum (January 1973), p. 41.

13 Ibid, p. 42.

14 "Where Time Moves at a Dizzying Pace," p. 174.

15 "To Market, to Market is RCA Lab's New Metto," Electronics (March 2, 1970), p. 95.

16 Second source agreement between Texas Instruments and Advanced Memory Systems, January 10, 1973.

17 Second source agreement between Texas Instruments and Advanced Memory Systems, March 16, 1972.

18 Stewart Warner, Texas Instruments Incorporated, "International Report on Microelectronics," memo, p. 4.

19 Electronic News, (April 10, 1961), p. 10.

CHAPTER 4

1 This coincides with the findings of other studies. See Tilton, op. cit., p. 77.

2 Patents as reported in Tilton, op. cit., Table 4-2, Semiconductor Patents Awarded to Firms in the United States, 1952-1968, p. 57.

3 Tilton, op. cit., p. 74.

4 Golding, op. cit., pp. 309-311.

5 Ibid.

6 Tilton, op. cit., p. 74.

7 Electronic News (November 27, 1969), section I.

8 Ibid.

9 Electronic News (November 29, 1973).

10 Ibid.

11 Electronic News (May 28, 1973), p. 70.

12 Golding, op. cit., p. 163.

13 Gene Bylinsky, "How Intel Won Its Bet on Memory Chips," Fortune, (November 1973), p. 184.

14 Ibid.

15 Second source agreement between Siemens and Advanced Memory Systems, June 11, 1972.

16 Executive of National Semiconductor interviewed for this study.

17 Vernon, op. cit.

CHAPTER 5

1 Estimated from data on offshore plants listed in Appendix C.

2 Y.S. Chang, Economics of Offshore Assembly: The Case of Semiconductor Industry, College of Business Administration, Boston University, faculty working paper, p. 31.

3 Y.S. Chang, The Analysis of the Offshore Activities of the Japanese Electronics Industry, International Bank for Reconstruction and Development, November 1972.

[4] Electronic News (September 11, 1972), p. 67.

[5] U.S. Tariff Commission, Economic Factors Affecting the Use of Items 807.00 and 806.30 of the Tariff Schedules of the United States (Washington: GPO, 1970), p. 9.

[6] Ibid.

[7] Electronic News, (March 24, 1969), p. 9.

[8] Robert E. Freund, "Competition and Innovation in the Transistor Industry," Duke University, Ph.D. thesis, 1971.

[9] If the American price in Europe was (Pa (1+T)-Pe)+Pa, the U.S. price would be the European price less the tariff or Pe/(1+t).

[10] Golding, op. cit., p. 221.

[11] G.W.A. Drummer, "Integrated Electronics Development in the United Kingdom and Western Europe," Proceedings of the IEEE (December 1964), p. 1417.

[12] Interview with John Tilton.

[13] Electronic News (April 15, 1974), p. 42.

[14] The ratio of the square footage of manufacturing plant to the total number of production employees was computed for a sample of 18 offshore assembly facilities (see Appendix C for a list of the plants) and also for 13 plants in U.S. (compiled from company documents and various issues of Electronic News). For offshore plants this ratio was 60 square feet per employee and for domestic plants, 175 square feet per employee.

[15] The capital-labor ratio for offshore operations was estimated in an indirect method.

CHAPTER 6

[1] Tilton, op. cit., p. 37.

[2] Factory sales includes exports but total exports includes sub-assemblies which are mostly excluded from factory sales. Therefore the ratio of total exports to factory sales overstates this percentage.

[3] Electronic News (December 9, 1957).

[4] Ibid (August 26, 1964), p. 22.

[5] Ibid. (June 6, 1966), p. 41.

CHAPTER 7

[1] Calculated from data supplied by the U.S. Department of Commerce.