PART TWO

CHAPTER FIVE

The Organizational and Geographic Configuration of the Personal Computer Value Chain

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Frederick Jameson (1991), in one of his ruminations on postmodernism, remarks that the personal computer (PC) comes up short as a visual emblem in an era that is, at least, in part defined by digital technology.[1] Notwithstanding the potent symbolism of the beige (or black) box, the PC falls short as an art object. And yet, the installed base of 500 million PCs worldwide not only provides desktop computing to hundreds of millions but also makes the PC the device that enabled the Internet to become more than just a curiosity for research scientists affiliated with universities and government laboratories. Even if it is not iconic, the PC has in some way touched every other industry discussed in this book, as it has become the ubiquitous information appliance, and the Dell business model has become universally admired. The production and distribution of the PC illustrates, nearly perfectly, the dynamics discussed in the Introduction.

The tension between the global and the local suffuses the PC industries and is derived from the modular design of the personal computer system. The physical components of the greatest value and technical virtuosity are the semiconductors and the hard disk drive. We omit the monitor in this statement, though as Murtha, Lenway, and Hart show in Chapter 7, the flat panel display (FPD) is certainly worthy of placement in this group of components. As Leachman and Leachman and McKendrick show, these two classes of components experience extremely rapid improvement, while the value of earlier generations decreases accordingly (Curry and Kenney 1999). For example, newly introduced semiconductors and hard disk drives (HDDs) experience a rate of technological obsolescence that decreases their value at up to 1 percent per week. Outside the electronics sector, as Abernathy et al. show, it may only be fashion-forward clothing that experiences a similar rate of value erosion. For the PC assemblers mastering this pace of change is vital for success. Excess inventory or transit time, delays of expensive components, or any finished or semifinished product containing them, anywhere in the value chain, results in value loss. A PC is like a "hot potato." Anyone holding it experiences value loss, while those holding it for less than the average time experience value preservation, which is captured as profit. Thus logistics capabilities are a central competency in the PC industry.

The desktop PC is the ultimate modular product (Langlois 1990; 1992).[2] Nearly every major component is a module (there are about ten to fifteen, including peripheral devices such as keyboards and monitors); this facilitates the disintegration of the value chain into separate firms. This modularity reinforced by open interface standards allows producers from low-cost environments to enter PC production absent other barriers to entry. In the competitive environment of component production created by modularity, the only firms to consistently make a profit have been Intel and Microsoft, precisely because they have been able to prevent entry (Borrus and Zysman 1977). This makes possible a second dynamic: a PC assembler is, in many ways, more a logistics coordinator than a manufacturer (Fields 2003). For example, with the exception of Dell and Gateway, all the major PC firms actually assemble only a fraction of their PCs; the remainder are outsourced to contract assemblers. But, more fundamentally, the assembly process adds little value, and the process is so routinized that proprietors of small shops and even individuals in their homes can undertake it. There are some exceptions to the disintegrated structure of the PC industry. Companies like IBM, NEC, Fujitsu, Samsung, and some other integrated computer makers do have internal operations that produce HDDs, memory chips, and other components. These firms are not dominant. Internal integration has not assisted their competitive status, and may, in fact, have hurt it. A more important form of integration is Microsoft's continuing strategy of integrating all PC-related software and Intel's use of its power in microprocessors (MPUs) to dominate the PCI bus chipset market, to become a significant producer of motherboards, and begin to integrate other functions such as graphics into the microprocessor.

The speed of change is one source of pricing pressure. To illustrate, it is not unheard of for Intel to declare that it will cut prices for a group of MPUs effective immediately or very soon by, say, 20 percent—or as much as 54 percent (Spooner 2001). This immediately devalues the MPUs in a PC firm's inventory by 20 percent, leading to a write-down. An equally important source of pricing pressure is the commodity status of the PC. There is little or no difference between a Dell, Hewlett Packard, or a no-name clone. The components and software are from the same sources, and are all available in the open market.

For a simple assembled product, the PC value chain is quite disintegrated. A PC assembler can produce an entire PC from scratch (very few do this currently), it can source an almost fully completed box, or it can ask a contract manufacturer to assemble the entire box and place the assembler's label on the box. And, in fact, many firms use a combination of these strategies. For example, Dell sources its least expensive computers directly from a Taiwanese firm that has a contract manufacturing operation in China, while assembling its higher-end PCs in its own factories around the world for that specific region. For other firms, such as HP and Compaq, contract manufacturers do the bulk of their production, mainly offshore.

Three articles (Leachman and Leachman; McKendrick; and Murtha, Lenway, and Hart) in this book deal directly with PC components, and, as they indicate, these are sourced globally. And yet, as we will show, much final assembly for the U.S. market is done in the United States or Mexico. The PC epitomizes globalized production in which development, design, manufacturing, and distribution are interlinked across vast distances—but which all operate on a time frame that seems more appropriate for firm clusters. In contrast to the clusters from which the component makers benefit, the geography of PC assembly is determined by the need to get the assembled unit to widely dispersed customers as quickly and as inexpensively as possible. By necessity the movement of large quantities of different parts and components from numerous, widely separated suppliers must be coordinated, even while operating under extreme time pressure. The PC must be delivered to markets whose variegated segments demand a variety of configurations and "solutions" to specific needs or problems.

It is not crucial for most suppliers to manufacture their product near the assemblers, nor for the assemblers to concentrate in any region, though Dell requires that its suppliers have warehouses (supply logistics centers) within twenty minutes' driving distance of its assembly operations. Also, where possible Dell sites its overseas assembly operations close to Intel's final testing and packaging operations.[3] However, what is most important is availability of a sophisticated multimodal delivery system capable of reliably moving time-sensitive components quickly and non–time sensitive products more slowly and inexpensively. The size and weight of the finished product, the downward pressure on both component and finished PC prices, and the complexity of the market all give an advantage to those assemblers who are, in terms of time and space, close to the final consumer.[4]

From the previous discussion, one might conclude that U.S. firms should have difficulty competing as PC assemblers. However, despite the fact that the PC is a highly standardized product, much of the manufacturing of the components occurs in Asia, and assembly is done by a variety of subcontractors in the United States and abroad. U.S. assemblers, especially the specialists, dominate the global market, and their share is growing.

Modularity, Speed, and Build-to-Order

In the 1990s, the PC contributed three ideal-typical concepts to thinking about business: modularity, speed, and build to order (BTO). In the case of modularity, it was scholars that were most influenced (Baldwin and Clark 2000; Langlois 2002). In the case of speed, many managers came to realize its significance, both in terms of speed-to-market, and the speed of change in components, their own products, and their markets (Fine 1998; Curry and Kenney 1999). For BTO, it was management thinking that was most affected (in the case of autos, see MacDuffie and Helper 2001; for garments, see Hammond and Kohler 2001).

The open-system modularity of the PC was, in large measure, due to a strategic mistake by IBM (Chposky and Leonsis 1988; Ferguson and Morris 1993; Langlois 1992; Steffens 1994). In the process of developing a microcomputer on a crash schedule, IBM decided that it needed to outsource many components including floppy disk drives (Tandon), power supplies (Zenith), circuit boards (SCI Systems), and the two critical components: the operating system (Microsoft) and the microprocessor (Intel). In the case of the first three components, most production would relocate to Asia. However, the two critical components would remain under the control of Microsoft and Intel.[5] IBM's decision to outsource the operating system and the microprocessor caused them to lose control of the PC, as all of the components became available in the marketplace. Microsoft negotiated an agreement with IBM that essentially gave Microsoft ownership to the operating system software, and Intel's microprocessor became the electronic core of the IBM PC. As merchants, therefore, Microsoft and Intel were both willing and able to sell to all customers, American and foreign. Although the PC was initially very profitable for IBM and for its first fierce competitor, Compaq, over time the PC became a commodity with the value-added captured by those making components protected by either insurmountable barriers of entry or intellectual property restrictions. Moreover, the standardized interfaces used throughout the PC made it easy to interchange components and peripherals. This was quickly exploited by Taiwanese manufacturers who were capable initially of doing only the lowest level of assembly work—but through this they could enter the industry and gradually upgrade their capabilities (Dedrick and Kraemer 1998; Levy and Kuo 1991). Modularity with open interface standards meant that for most modules there were no non-market barriers to new entrants.

Modularity ignited what Bresnahan and Richards (1999) termed "vertical competition," in which every firm in the value chain strives to commoditize the other segments of the value chain. The much-vaunted Wintel duopoly is not an exclusive arrangement.[6] Microsoft gladly qualifies other MPUs to run its software such as the new Transmeta MPU, while Intel is anxious to support other operating systems such as Linux. Because lower prices encourage greater sales, every firm would like the overall price of a PC system to drop; their only wish is that the cost reduction occurs at other segments in the value chain. This means that new entrants can emerge from almost anywhere in the world. As long as they conform to the publicly available standards, have adequate quality, and deliver as promised, even the world's largest PC vendors might purchase from them.

The PC industry operates in a condition of constantly declining component prices, with a constant models turnover. The falling price and time constraints are caused by both rapid technological change and the diverse market-driven nature of PC component production. If PC production were completely vertically dominated by a few large companies, then it might be possible to contain rapid change and introduce new innovations in an orderly fashion. In a market characterized by vertical competition, high profitability is possible only in the high end of the market, but any given performance level is at the high end only transiently before being commoditized and rapidly losing value. This dynamic is halted only when the product is sold to the final consumer (and does not come back as a return). There are two implications of the value erosion dynamic that are important for this chapter. The first implication is that powerful advantages will accrue to any firm that can shorten the period during which it holds inventory. The second implication is that rapid transportation of product containing high-value components is vitally necessary, so low production cost cannot be the only criterion in cost calculations. Time is a vital dimension influencing the location of various production activities.

Given these dynamics, there were a number of responses, most of which were a variant on outsourcing. However, another model emerged that has been termed the BTO direct marketing model as practiced by Dell Computer and Gateway Computer. The BTO model is predicated upon a population of experienced consumers willing to purchase a computer on the basis of a series of specifications without in-person examination—in other words, consumers who treat a PC as an entirely standardized commodity; in the case of Dell, this represents close to 80 percent of its total sales. These consumers permit the

BTO practitioners to build computers only after they have been ordered. Therefore, Dell orders the components only after receiving an order. For this reason Dell carries little inventory, because it has contracted with its suppliers to pay for components upon arrival at Dell's factory. Even better, Dell has already locked in the price. Also, since the consumer has ordered the computer, it is likely that they will keep it and not return it, thereby substantially reducing the amount of returned (and hence greatly devalued) product. What the BTO firms have developed is a model designed to exploit the PC's modular design and its concomitant value erosion dynamic.

It is useful to view the component supply system from the perspective of the assembler. The PC as a final product is relatively bulky and heavy. This is in part because it was designed for ease of assembly and thus was not as compact as it could have been (see the early Apple IIs, Macs, or notebook computers for the alternative tight physical design). The valuable components in a PC (MPU, DRAMs, HDD, and chipset) occupy an area that is only some 10 percent of the total volume of the box. If the motherboard and the high-value graphics cards are added, the total space occupied might be one-fifth of the box. The small size of these valuable components allows them to be inexpensively shipped by air to any location. The larger and heavier components and peripherals with lower value compositions, such as cases and keyboards, can be shipped by cargo container. Since the assemblers are concerned with both supply *and* distribution logistics, and the most important components are shippable by air, physical proximity to suppliers is not critical, though it might be convenient. For example, Dell's European assembly operations in Ireland are located close to Intel's Irish factory.[7] However, assurance that all components (including those of low value) will arrive as scheduled is vital. Dell has tackled this problem by requiring all of its suppliers (except Intel) to have a warehouse within twenty minutes of its assembly facilities.

The Personal Computer Industry

The PC, in its manifestation as a beige box, is the result of one of the simplest assembly processes in contemporary manufacturing. Modularity and internal standardization has proceeded to such an extent that an assembler with minimal training can assemble a PC in fifteen minutes with little more equipment than a screwdriver and a socket set. The most sophisticated moving device is the HDD, which is a sealed box that is inserted into the computer to be held in place by four screws and has a power socket and a data cable socket. The power supply is attached prior to the assembler's receiving the case, and the various power supply wires emanating from it need merely be plugged into the appropriate module. With the integration of some subsystems onto the motherboard during the 1990s, and the introduction of USB ports in the late 1990s, assembly became even simpler. In terms of manufacturing, the PC firms merely purchase and assemble the components and install the software.

Given the simplicity of the final assembly process, the consumer desiring a new PC has numerous options: it is possible to build it yourself. It can be built by the local PC store. It can be purchased at a computer chain store from a mass producer such as HP or eMachines who either assembled it or had a subcontractor assemble it, or it can be purchased by telephone or over the Internet from one of the build-to-order, direct marketers such as Dell or Gateway, which then assembles it and delivers it to your door. Each channel contains essentially the same product, and all have one thing in common—nearly all of the manufacturing is done elsewhere by the component firms, and sometimes all of the assembly is done by another firm. For example, in 2002, IBM announced that it would no longer manufacture any desktop computers—that is, the only physical relationship IBM has with the computer is the IBM badge that the subcontractor places on the machine. Given the lack of differentiation and the simplicity of assembly, the only areas available for differentiation by the PC firms are more efficiently organizing their supply chains, more effectively managing their marketing channels, and managing their brand.

As a condition of survival, PC firms must incorporate the latest technology (innovated elsewhere and available simultaneously to competitors) and assemble and deliver the PC to the market as quickly as possible. The only other ways for these companies to generate value beyond that which they derive from the boxes they sell is diversification, or in an ancillary strategy, to outsource their PC assembly work and concentrate on marketing and downstream logistics. Virtually all the major PC assemblers have pursued variants of this; examples are Compaq's acquisition of DEC and HP's successful entry into the market by using their marketing skills, brand name, and existing distribution channels while producing very few of their own PCs. Other examples of change are HP's recent acquisition of Compaq, and IBM's retreat from manufacturing PCs and decision to stop selling consumer PCs through standard retail channels, while converting most of its marketing efforts to business users and Internet sales. The companies that have had the most success dealing with the problematic nature of the PC as a commodity have been the direct marketers, most notably Dell and, until recently, Gateway.[8]

The key components in a PC, with the exception of the software, lose value as rapidly as fresh produce, prompting the founder of Acer, Stan Shih (1996), to compare the PC industry to the fast food industry. Like a fast food hamburger, the final assembly of the PC should take place as close as is economically feasible to the final consumer. The perishable components can be produced in distant locations as long as they can be economically airlifted to the final assembly site. The logic of the PC industry seems to turn conventional geographical patterns of production upside down. Unlike many electronic products, which are assembled or fabricated in low–labor cost regions and then shipped to market in high–labor cost regions, the low value-added operation of assembling a PC is undertaken in relatively high–labor cost areas. While some PC production for the U.S. market has shifted to Mexico (Acer in Ciudad Juarez for example), or to contract manufacturers in the U.S. South, it is still relatively close to the intended market—and labor costs are much higher than those in China, to where a significant amount of board-level component manufacture and low-end PC assembly is being relocated. There is one exception to this pattern: the cheapest machines using components that are almost entirely depreciated are now built in China.

Business Models

The PC industry is curious, because nearly twenty years after its introduction, though there has been consolidation, there is as of yet no dominant model for firm organization—though recently Dell is, perhaps, becoming the dominant firm. In Table 5.1, we parse the PC industry into seven basic business models, though it should be recognized that these are ideal-types and there are other variants, and there has been significant experimentation with yet other models, especially in the area of employing the Internet (Kenney and Curry 2001). These models provide insight into the different organizational configurations that PC assembly can adopt and how differently they may organize assembly, distribution, and marketing. Therefore, it should not be surprising that there were a wide variety of entrants with differing strategies, both spatially and organizationally. Some of the most critical decisions assemblers had to make were whether to make or buy the PC, where to locate their assembly facilities, and how to organize their finished product distribution. Finally, given the component devaluation dynamic, assemblers had to consider how long they held inventory—so spatial location was not irrelevant because a temporally inefficient location can lead to excess devaluation.

Another issue is how to interact with the final consumer. This decision is important, because it has contributed to different make-or-buy and location decisions. The traditional distribution method had the PC firm undertake final assembly in its own factory or in a subcontractor's factory and then deliver the PC to a retailer. The mass assembler interacted with customers through the retailer, a common method, yet one that presents difficulties for interorganiza-

TABLE 5.1
PC Assembler's Business Models

Category/Model	Characteristics	Main value leverage	Examples
1. Retail assemblers (value-added re-sellers)	Small local shops ("screw-driver guys"); some with fairly large accounts; col-lectively account for 25% market share	Know local market; best at customer service; low pro-duction overhead	
2. Standard mass as-semblers	Inputs shipped to central facility; long-term produc-tion planning; marketed through standard retail/ VAR channels	Traditional scale econo-mies; brand identity. More recently, OEM from Cate-gories 3, 4, and 5	IBM, Compaq, HP, Siemens, Sony, NEC, Fujitsu, Samsung
3. Contract manufac-turers	OEM assemblers for large branded marketers (standard mass producers)	Efficient production, en-able large branded assem-blers to expand production while minimizing risks	Solectron, SCI Systems, Jabil Systems
4. Global logistics producers	Assembled at dispersed lo-gistics centers; monthly or weekly production plan-ning; direct shipment to channels bypassing OEM customer	Input and distribution logistics on global scale, provision of OEM and ODM services	Acer, FIC, Mitac, Tatung
5. Channel assemblers	Quasi-logistics centers for standard mass producers; handle excess capacity for mass producers; handle service, integration, con-figuration for large accounts; alternate retail channel	Distribution logistics, service to customers, system integration	Ingram Micro, Micro-age, Tech Data
6. BTO/Direct Marketers	Inputs assembled at central facilities; production plan-ning on per-order basis; di-rect shipment to customer	Mass customization; pro-tected from price declines	Dell, Gateway, Micron (defunct)

Source: Authors' compilation

tional information flow. This can be further exacerbated when there is a subcontractor for final assembly, making informational transparency issues even more complicated. The BTO model has a direct relationship to the customer; there are no other intermediaries, thereby providing the BTO firm with the most contemporary and unmediated information.

PC producers exhibit only limited apparent clustering or agglomeration. The major producers' central production facilities are located in a variety of places: Texas (Dell and Compaq), and South Dakota (Gateway). They also rely on numerous original equipment manufacturer (OEM) electronics contract manufacturers scattered around the country. Two global logistics firms, Taiwanese PC producers FIC and Acer, have located plants in Austin, Houston, and El Paso, Texas, and Ciudad Juarez, respectively. The global contract manufacturers Solectron, Sanmina, Flextronics, SCI Systems, and Jabil Circuit have numerous locations around the world. These companies produce both components and assembled PCs. The mass assemblers also use the services of various distributor-VARs. One of these, Ingram Micro, operates an assembly/integration center in Memphis, Tennessee. Ingram's six other distribution centers, dispersed throughout the United States, also engage in some assembly and configuration activities. While some of the OEM assembly facilities are located near the major assemblers, there is no specific reason for them to be, since the assembled PCs are shipped directly to retailers and VARs—and in some cases to the final customer. Distributors like Ingram also perform some assembly functions by colocating at an assembler's plants. As for the major assemblers themselves, three of them (Compaq, Gateway, and Dell) have their main assembly facilities, and two of the three (Compaq and Dell) have their headquarters, in the cities in which their founders lived at the initial startup. Gateway was founded in North Sioux City, South Dakota, and has an assembly facility there; in 1998 its headquarters moved to San Diego, though it has no production facility there.

Since the core components are small and can be shipped in from distant locations, and finished PCs are large enough to incur significant transport costs, there is no driving logic to locate suppliers in vertical production clusters. Component supplier or distributors' representatives can be stationed at the assembler's plant in order to coordinate the inflow of components from more distant locations. There are instances where suppliers have set up facilities near their major customers, but it is far more likely for companies that engage in downstream configuration functions to locate operations in or near a major assembly facility. The dispersed location of large-scale PC assembly reflects the dispersed nature of PC assembly in general. More significant than having suppliers in close proximity is proximity to adequate transportation hubs, especially air cargo. For example, Ingram Micro located their assembly and configuration facility near to the Memphis airport, which is the hub for Federal Express. In the United States there does not appear to be any benefit in large assemblers locating in close proximity to each other, and there are no clusters.

Retail Assemblers

To understand the industrial dynamics of PC assembly, it is useful to begin with the retail assembler category that is invisible, but continues to supply at least 25 percent of the entire market. Given the ease of assembly and the wide availability of components, it is easy to enter the PC industry, as Michael Dell proved by beginning his business assembling PCs in his University of Texas dormitory room. These small local shops, once referred to by Steve Ballmer of Microsoft as the "screwdriver guys," can be found in almost any city and in many small towns. Collectively, these local "beige" or "white box" producers (also known as value-added resellers, or VARs) have a 25 percent market share in the United States and an even greater share in many other countries.[9] According to *Reality Research and Consulting* (2000), an estimated 5.62 million white box PCs were sold in North America in 2000. These systems were sold by a motley collection of some 28,800 solution systems integrators, consultants, and value-added resellers. They range from small shops that might produce only a few PCs per week to much larger operations that have contracts to supply local businesses with PCs and other computer-related equipment. These producers operate with lower overhead than the large assemblers and deal directly with customers without the costs of maintaining a large, geographically dispersed technical-support staff or support call centers. The VAR category also consists of numerous other firms that do some kind of assembly or configuration work and are situated in the distribution channel either as technology distributors or integrated information technology service providers.

These firms have survived for two main reasons. First, because of the open market for parts and components, they are able to offer systems similar in quality and price to those of the large assemblers.[10] One major distribution channel for parts is firms such as MicroAge, Ingram Micro, and Tech Data, which also provide channel assembly services. While the retail assemblers do not have the ability to negotiate lower prices for volume purchases, they also do not have the high overhead (including transportation) that large firms do. The second reason is that they are close to their customers. That is very important. Many of these customers demand more than assembled boxes; quite often they are looking for vendors able to provide design, coordination, consultation, and ultimately, complete specially configured systems. The VARs and system integrators, which do this kind of work, may provide completely assembled systems from the major assemblers, as-is or reconfigured, or they may assemble their own systems. The services provided by local and regional VARs are particularly important for smaller enterprises that may not be willing pay the high fees that the larger consultancy firms charge. Moreover, when there are problems, the customer can go directly to the provider and need not deal with large, impersonal service departments (a number of which have also been outsourced). These small assemblers form the base of the industry, and have proved remarkably persistent.

Mass Assemblers and the Contract Manufactures

The traditional competition for the retail assemblers was the mass assemblers exemplified by IBM and Compaq. These firms operated on a quarterly plan that estimated the number of PCs in every category that the market could bear, and then built (or subcontracted) to the plan. The product was built, pushed into the channels, and then the assembler hoped that the plan was accurate. If the plan was too optimistic, the resulting inventory gluts were eliminated by massive discounting. If the plan underestimated demand either in an overall sense or in certain models, there were general product shortages or shortages of a particular model.

The mass assemblers relied heavily upon three other models listed in Table 5.1—that is, contract manufacturers, global logistics firms, and channel assemblers—to undertake some or much of their actual assembly. The involvement of these other assembly models was not confined to subassembly. Significant percentages of the mass assemblers' entire production were completely subcontracted to OEMs. Thus, in many respects, for some models in their product lineup, the mass assemblers, especially HP and IBM, are merely mass marketers, and their most important contribution to the product is their brand name.

To illustrate how important subcontracting has become, in 2000 Compaq Computer imported $9.5 billion worth of components from Taiwan alone. This compared with Compaq's total sales, which were $35.6 billion in fiscal year 2000. In 2000, Compaq was Taiwan's top PC OEM client, outsourcing everything from motherboards and monitors to power supplies and notebook systems. The number of Taiwanese firms providing Compaq was remarkable. One Taiwanese firm, Inventec, made Compaq's Armada business notebooks; Arima Computer produced most of the Presario consumer notebooks; and Quanta was considered as a potential notebook supplier. Mitac and FIC produce desktop PCs, and cathode ray tube (CRT) and FPD monitors for Compaq globally. To service Compaq, FIC has a major assembly complex in Texas (Custer 2001).

The mass assemblers and contract manufacturers are dispersed throughout the United States. The one firm assembling PCs along the border, Acer in El Paso and Juarez, mostly produced PCs on an OEM basis for IBM. When IBM cancelled its Aptiva line, the Acer Mexican facility was adversely affected, and the El Paso factory was closed (Bloomberg News 2000b). The contract manufacturers produce a variety of PCs, workstations, and servers for large PC mass assemblers such as Compaq, IBM, and Hewlett Packard, as well as numerous smaller brands and "beige box" nonbranded PCs. U.S. mass assemblers produce a significant number of PCs for the U.S. market in Guadalajara, Mexico. There, major brand-name firms like IBM and Hewlett Packard produce finished PCs, along with workstations/servers and notebooks, for export. They are also joined by the U.S. contract manufacturers, most of whom have established facilities in Guadalajara in the past few years; from there they supply not only finished PCs to the mass assemblers but also components to the U.S. assembly facilities of Dell, Compaq, and various other firms.

During the mid 1990s, there was a general movement of the Taiwanese Global Logistics Producers to locate final assembly in North America as part of an effort to meet the demand for speed to market and to decrease the retention time of a PC. However, from 2000 onward, Taiwanese firms began shifting assembly from bases closer to end markets (the United States and Europe) to low-cost areas such as China. For example, in 1999, 30 percent of all the PCs produced by Taiwanese firms were assembled in North America, but this shrank to 25 percent in the first quarter of 2000. China increased to second in the first quarter of 1999 with 27 percent of Taiwanese assemblies, and rose to first place with 37 percent in the first quarter of 2000 (Computex Online 2001). The reason for this is that the constant cost pressure combined with the fact that for a low-end machine that cost, say, $600 retail, even if it declined in value at 1 percent a week, it lost only $18.00 in three weeks. There are other advantages to production in China beyond labor costs. The most important of these is that a finished Chinese computer can be shipped directly to its retail outlet in the United States, whereas final assembly in North America requires all the components be shipped to the North American factory, to then be unpacked and assembled. For low-end systems, the savings on depreciation may not outweigh the extra shipping costs and the higher cost of labor in Mexico or the United States. So it is possible that final assembly for the traditional retailers could, once again, shift overseas.

The mass assemblers have out-sourced production of the entire PC to contract assemblers in a bid to lower costs and to displace risk. This strategy has permitted them to lower costs; however, the PC and its components are still subject to devaluation as they progress through the value chain to the retailer and then the final consumer. Nevertheless, the temporally based devaluation continues, and even assembling in the low-cost Chinese environment cannot circumvent this reality; therefore a business model that overcomes the temporal devaluation dynamic will, ceteris paribus, have a profound advantage.

Build to Order

The BTO model pioneered by Dell and Gateway directly addressed the temporal devaluation dynamic.[11] Here, computers were assembled only after the consumer's order was received. This reduced risk substantially, because it was no longer necessary to build to a projection of consumer demand, ship the inventory into the channel, and then wait to see what sold. In the BTO system, the

PC assembler receives immediate consumer feedback on what is selling and thus can adjust projections immediately. This information can be transmitted directly to suppliers, thereby providing them with near real-time information on sales. That permits the supplier to adjust more rapidly to market changes, creating greater overall transparency in the entire production chain. As with the retail assemblers, the BTO firms assemble all of their desktop PCs, and do not use any contract assemblers for final assembly. Internal assembly provides them with complete control of the customer order fulfillment cycle, eliminating dependence on external organizations.

The BTO model exposes the reason that clustering is not a powerful dynamic in the PC industry. Proximity to the customers, who are widely dispersed, is the most important competitive advantage. The whole point of the BTO model is to bring assembly as close to the customer as possible. This is not limited to proximity in the physical/geographical sense; it also refers to proximity in the organizational sense. One of the BTO firm's most important advantages has been the fact that they interact directly with the consumer and assemble the system only upon a customer's order. This means they have disintermediated all of the distributors and retailers standing between conventional assemblers and customers (Curry and Kenney 1999).

The Globalization of the U.S. PC Firms

One might expect that in a commoditized industry and with many powerful Asian competitors, U.S. firms would be at a disadvantage. However, the opposite is actually true. U.S. PC assemblers have been gaining global market share (in terms of units sold) at the expense of their overseas competitors. In Europe, U.S. firms have gained market share and driven local vendors from the marketplace. Today, in most nations outside of Asia, the competition is increasingly among U.S. PC firms. In Asia, the competition is between various national firms and the globalized U.S. firms.

The first global PC vendor, not surprisingly, was IBM, which used its global network to market PCs. Until the early 1990s, in most foreign markets IBM did not face the U.S. clone makers; rather it faced national computer firms and some—though far fewer than in the United States—white box assemblers. In Europe its primary competitors were the various national champions such as Olivetti in Italy, Groupe Bull in France, Siemens in Germany, and ICL in Britain. In the Japanese market, the competition was more severe, because IBM faced the entrenched Japanese computer firms such as NEC, Fujitsu, and Hitachi, to name the most prominent. In Korea, IBM faced a closed market that was reserved for domestic manufacturers. So, until the early 1990s, IBM was the most global of the PC vendors. Korean and Japanese firms made repeated efforts to penetrate the U.S. market. However, after some initial success, they invariably failed to consolidate their gains and were forced to retreat, except in notebook computers.

The success of the U.S. firms in global markets is best illustrated in Table 5.2. As did Compaq earlier, Dell gained market share in the United States and then went on to capture the global market share crown. The increased rank of Fujitsu/Siemens and NEC in 2002 is due to the HP/Compaq merger. They are continuing to lose global market share. With the U.S. market saturated, all the PC assemblers looked to foreign markets for growth. Table 5.3 indicates how far-flung these operations are. But it also shows that Gateway was forced to close its overseas operations because of competition from Dell and HP/Compaq. For the European market, the primary assembly location has been Ireland and Scotland. The reasons for this were a combination of government subsidies, relatively low wages, and a preference for locating in English-language environments. In Latin America, the pattern was different, with Brazil and Mexico being the two largest hubs. HP and IBM have their most important Latin American production facilities in Guadalajara, a legacy of an earlier local origin requirement that Mexico imposed on the computer industry. However, business was so difficult that in 2000, IBM sold its Brazilian manufacturing operation to Solectron (Solectron 2000).

The first major U.S. PC start-up to enter foreign markets was Compaq,

TABLE 5.2

Global Ranking of PC Sales by Units, Third Quarter 2002, 2001, 1999, 1997, and 1990

Ranking	1Q, 2003	2001	1999	1997	1990
1	Dell	Dell	Compaq	Compaq	IBM
2	HP/Compaq	Compaq	Dell	IBM	Apple
3	IBM	HP	IBM	Packard Bell NEC	NEC
4	Toshiba	IBM	Packard Bell NEC	Dell	Compaq
5	NEC	Fujitsu/Siemens	HP	HP	Toshiba
6			Gateway	Gateway	Olivetti
7			Apple	Apple	Groupe Bull
8				Acer	Fujitsu
9				Fujitsu	Unisys
10					Commodore
11					HP
12					Dell
13					Packard Bell
14					Gateway 2000

Source: Various journals.

TABLE 5.3
Global Location of U.S. PC Firms Factories

Company	U.S. factories	Compaq direct	Asia factories	Configuration centers	Latin Amer. factories	Europe factories	Australian factories
Compaq[a]	Houston, TX; Fremont, CA	Ontario, CA; Omaha NE; Indianapolis IN; Swedes-boro NJ	Singapore	Bangalore, India; Akiruno-City, Japan; China	Sao Paulo, Brazil	Ayr, Scotland; Erskine, Scotland	Sydney, Australia
Dell	Austin, TX; Nashville, TN		Penang, Malaysia; Xiamen, China.		Eldorado do Sul, Brazil	Limerick, Ireland	
Gateway	North Sioux City, SD; Hampton, VA; Salt Lake City, UT		Malacca, Malaysia (defunct)			Dublin, Ireland (defunct)	
Hewlett Packard[a,b]			Singapore; China	Bangalore, India	Guadalajara, Mexico	Netherlands	
IBM[b]	North Carolina		Japan; China		Guadalajara, Mexico	Scotland	

Source: Authors' compilation
[a] With the merger of HP and Compaq, we expect many of these will be closed. However, this has not yet been announced.
[b] There was insufficient information for a complete listing as large integrated firms do not report their PC factories separately.

which began selling PCs in Europe in April 1984, less than two years after its formation. In November 1987, Compaq opened its first overseas manufacturing facility in Scotland. However, as in the United States, Compaq's operations gradually evolved from relatively integrated production to one in which they outsourced even more of their global operations. So by 2001, Compaq and HP had the Taiwanese firm FIC producing hundreds of thousands of desktops a month in the Czech Republic (Hung 2001).

Dell also moved into the global markets relatively early. Beginning in 1987 it opened a sales subsidiary in the United Kingdom, and followed that in 1990 by opening a manufacturing center in Limerick, Ireland, to serve European, Middle Eastern, and African markets. In 1996 an Asia-Pacific manufacturing center was opened in Penang, Malaysia, followed in 1998 with a production center in Xiamen, China. In 1999 a manufacturing facility in Eldorado do Sul, Brazil, was established to serve Latin America. In relative terms, Dell lagged Compaq in globalizing. However, the important point is that like IBM, Compaq, and HP, Dell now operates globally.

The Asian market is the most interesting from the perspective of globalization, because it is the home of a number of powerful computer firms, ranging from the Japanese and Korean mass assemblers to the Taiwanese global logistics producers. Finally, the fastest growing PC market in the world is China, and its leading firm, Legend Computer, is growing rapidly and may soon enter the ranks of world leaders. However, even in China, Dell now ranks seventh in sales.

With the exception of IBM, U.S. PC makers benefited from two attributes of the U.S. market. The first was its huge size. Probably more important was the fact that almost invariably, key hardware and software, especially the new killer applications, were developed—or, as was the case for the World Wide Web, were adopted—most rapidly there. So, U.S. PC makers were privy to the latest trend. This was not the only advantage. As Microsoft and Intel integrated the world under one standard, U.S. makers were able to penetrate new markets on their heels. For example, Microsoft unified Japan under the Windows standard, and made the NEC 9800 DOS standard obsolete (West and Dedrick 2000). This stratagem provided an opportunity for U.S. vendors such as Dell and Compaq to enter the Japanese market; though Fujitsu retains the greatest market share, U.S. vendors achieved a foothold.

Although the U.S. firms are not dominant in Asia, they hold such a commanding lead in the rest of the world that they are becoming globally dominant. The globally dominant position of the U.S. PC firms is not difficult to understand, as they were able to use the knowledge and brand name recognition gained from operating in the competitive U.S. markets. Also, as they grew in size they were able to reap the benefits of volume discounts that were much greater than any other national firm could achieve. These advantages have allowed them to gain market share even in Asia, a region in which many strong PC firms already exist.

The Globalization of PC Component Markets

The market for PC components is global, but the geography of PC component production is essentially Pacific and includes the U.S. West Coast, Northern Asia, China, Southeast Asia, and, to a lesser degree, Mexico.[12] The remainder of the world is largely irrelevant. However, within this Pacific realm, locations undertake both the production of different components and parts of the value chain, as is shown so well in the chapters on HDDs, FPDs, and semiconductors. Moreover, as these chapters indicate, the location of many of these activities has been shifting through time. Remarkably, other activities, especially design, as some of the other chapters indicate, have remained rooted in places such as Silicon Valley.

The PC consists of a hierarchy of components, each with its own value composition and its own vulnerability to obsolescence. While there is a great variation and complexity in the actual production linkages, it is possible, at least for

TABLE 5.4

The Value and Time Sensitivity of Personal Computer Components

Key components	Value	Time sensitivity
Proprietary		
Operating System	High	Low
Microprocessor	High	High
Commodities		
FPD	High-Medium	High
Memory (SRAM, DRAM, EPROM, etc.)	Medium	High
Hard Disk Drives	Medium	High
Monitors	Medium	Medium
Secondary Higher Value Components[a]		
Video/Multimedia Chips and Card	Medium	High
Mainboard Chipset and Mainboard	Medium	High
BIOS Chip	Medium	Medium
Communications Chips and Card	Medium	Medium
Commodity Components:		
Floppy Disk Drive	Low	Low
Keyboard and Mouse	Low	Low
CD-ROM Drive Assemblies	Low	Low
Cases	Low	Low
Power Supplies	Low	Low
Connectors, Cables, etc.	Low	Low

Source: Compiled by authors from *Electronic Business Asia* (August 1996).

[a] The value of these printed circuit boards is almost entirely in the chips in the previous category.

illustrative purposes, to conceptualize four levels of components (see Table 5.4). Each component reflects either an international or regional spatial division of labor, or both. Also, as we indicated above, in terms of components there is an organizational division of labor, because only a few of these firms have integrated the disparate parts of the PC value chain. As mentioned earlier, IBM and the large multidivisional Asian computer/electronics firms such as NEC, Fujitsu, Toshiba, Hitachi, and Samsung do or did produce a variety of capital-intensive components such as HDDS, DRAMs, monitors, and FPDs in a variety of locations around the globe. The competencies for component manufacturing have not translated into success in the PC industry. The converse seems also to be true—that is, PC assemblers, in general do not appear to have been successful in integrating into component production. For example, Compaq produced a number of its own components during the 1980s, but then in the early 1990s it had to retreat. Similarly, Acer believed it could produce components for its PCs, but these efforts had limited success.

Key Components—Proprietary

The first level of components, the operating system and microprocessor, are "proprietary." By this we mean that the product is strongly defended by various forms of intellectual property protections, or also in the case of Intel, manufacturing scale-related barriers to entry, that have been persistent and difficult to overcome. The production (or development) of PC operating systems for the mass market is dominated by one firm, Microsoft, whose operations are predominantly in the United States. As of June 30, 2000, of the 39,100 people Microsoft employed on a full-time basis, 27,000 worked in the United States and 12,100 were employed overseas, a significant number of which were in sales and marketing related positions (Microsoft 2000). Even more important, Microsoft

TABLE 5.5

Financial Results for Selected Firms in the PC Value Chain, 2000

Company	Net revenues	Operating Incoùme	OI/NR	Products
Microsoft	23,845	9,624	.4036	OS/apps.
Intel	33,726	10,535	.3124	Microprocessor, chipsets, mainboards
AMD	4,644	1,029	.2216	Microprocessor, SRAMs
Samsung Elect.[a]	27,145	4,762	.1741	DRAMs, FPDs, CRTs, etc.
Micron Tech.[b]	7,584	1,515	.1998	DRAMs
Seagate	6,448	(561)	N/A	HDDs
Quantum	4,749	180	.0379	HDDS
Western Digital	1,961	(98)	N/A	HDDs
Maxtor	2,705	32	.0118	HDDS
VIA Tech.[c]	950	201	.2116	Chip sets
Asustek	2,136	473	.2214	Mainboards/graphics boards
Creative Tech	1,369	150	.1069	Graphics chips/boards
ATI Tech.	1,309	139	.1062	Graphics chips/boards
Nvidia	735	100	.1361	Graphics chips
Accton Tech.[d]	296	15	.0507	Comm. chips/board and hubs
Logitech	761	48	.0631	Input devices
Dell	31,888	2,310	.0724	PCs
Compaq	42,383	569	.0139	PCs
Gateway	9,601	242	.0252	PCs
Acer	4,761	205	.0431	PCs, OBM/OEM
Legend	3,490	110	.0315	PCs (China)
Trigem Comp	3,176	(13)	N/A	PCs (Korea and export)
Mitac	4,983	74	.0149	PCs OEM
Quanta Comp.	2,511	259	.1031	Notebook PCs OEM
FIC	2,308	7	.0030	PCs OEM
Ingram Micro	30,715	226	.0075	Distri. and OEM assembly PCs, parts etc.

[a] DRAMs accounted for only 25 percent of total sales, though it was the most profitable area for Samsung. In 1999, Samsung⊗ DRAM sales were $10.6 billion. These certainly grew in 2000, but were falling dramatically in 2001.

[b] Micron Technology had PC sales in 2000 of $1.066 billion with a net loss of $146 million. If these were removed from Micron⊗ results its profit rate would be significantly higher (Micron Technology 2000) Source: Compiled by authors from *Electronics Business* (August 2001).

[c] Original earnings were in NT$; these were converted to U.S.$ at NT$ 32.5 = $1.

[d] These are 1999 earnings, which are the latest available. U.S.$ 1 = 32.5 NT$.

is the most highly profitable firm in the PC value chain and has no strong competitor (see Table 5.5). It does little subcontracting, preferring to integrate as much of its process in-house as possible. It even undertakes its disk duplication internally in a facility in Humacao, Puerto Rico (ibid.). Microsoft is integrated both organizationally and spatially, undertaking most of its value-adding activities, as opposed to sales and marketing activities, in the Seattle area.

Intel dominates the PC MPU market, though it does experience competition from Advanced Micro Devices (AMD). As the chapter by Leachman and Leachman indicates, the MPU value chain is more dispersed than that of Microsoft. However, the headquarters for Intel, AMD, and a new competitor, Transmeta, are all in Silicon Valley.[13] According to Intel, 70 percent of its wafer production is conducted within the United States, in New Mexico, Oregon, Arizona, California, and Massachusetts. Another 30 percent is undertaken in Israel and Ireland. Intel also manufactures microprocessor- and networking-related board-level products and systems at facilities in Malaysia, Oregon, and Washington. "A substantial majority of [Intel's] components assembly and testing, including assembly and testing for microprocessors, is performed at facilities in Costa Rica, Malaysia, and the Philippines" (Intel Corporation 2002). They also are expanding a component assembly and testing facility in China. Subcontractors are used to assemble chipsets, but not the core microprocessors. According to Intel, a substantial majority of the design and development of components and other products is performed in the United States at their facilities in California, Oregon, Arizona, and Washington. Outside the United States, Intel has significant product development facilities in Israel and Malaysia (ibid.). AMD has substantially the same profile. Because of its smaller size, it has fewer production sites, though it does have one in Europe. These firms, though their operations are globalized, continue to draw upon their Silicon Valley roots.

The strength of Intel and Microsoft can be seen from Table 5.5 in two ways. First, though these are crude measurements, it is clear that these two firms capture as much profit as all the other firms in the PC industry do. In addition to capturing the largest mass of profits, Intel and Microsoft profit rates of 31.2 percent and 40.4 percent of revenues, respectively, are significantly higher than those of other firms. There are differences between Microsoft and Intel. Most important, Intel does have competition, while Microsoft experiences none. Also, whereas Intel's MPUs do experience dramatic price declines over their life cycle, Microsoft is able to hold the price of its software steady during the entire product cycle! More remarkable, as the average price of a PC has been declining, the operating system price has remained constant, thereby increasing as a percentage of the entire system cost. In terms of globalization, it is apparent that these two U.S. firms realize the lion's share of the profit in the entire value chain, and respectively are the most profitable software and semiconductor firms in the world.

Key Components—Commodities

The second level of key components varies in their level of technological sophistication. As McKendrick shows, HDDs contain precision machined moving parts and solid-state integrated circuitry. Memory modules consist of DRAMs mounted on small, pluggable circuit boards. FPDs are hybrid solid-state devices that have been difficult and expensive to manufacture but are rapidly decreasing in cost (see the chapter by Murtha, Lenway, and Hart). CRT-based computer monitors are based on television tube production (for a further discussion, see the chapter by Kenney). The difference between these products and the prior level is that though they are high-technology commodities, they experience brutal price competition. Therefore profits are both cyclical and concentrated among the first movers with the most capable products and greatest production efficiencies.

The globalization of FPDs and HDDs is explained in other chapters. In the case of DRAMs, as Leachman and Leachman point out, the only U.S. manufacturer left in the industry is Micron Technology. Micron is also globalized, though its main operations remain in Idaho. Micron operates a fabrication facility in Avezzano, Italy, and a module assembly and test facility in Scotland. Finally, in Asia it acquired its Japanese joint venture fabrication facility and operates an assembly and test facility in Singapore (Micron Technology 2000). The only major European-owned DRAM producer is Infineon, which was spun out of Siemens. Infineon also has DRAM operations in Europe; Richmond, Virginia; and Hsinchu, Taiwan, with a number of assembly and test facilities scattered around the world (Infineon Technologies 2000). With the exception of Micron and Infineon, the remainder of the DRAM producers are headquartered in Asia, especially Japan and Korea and, to a lesser degree, Taiwan. The world's leading producer is Samsung, and it is profitable when DRAM prices are strong. However, the most interesting thing about DRAMs, as Leachman and Leachman indicate, is how difficult it is to remain consistently profitable. For example, in the twelve months that ended in August 2001, the cost per megabyte of DRAMs dropped 90 percent. Most of the Japanese firms have been shifting their product mix away from DRAMs or consolidating their operations. For example, Hitachi and NEC created a joint venture in an effort to cut costs. In Korea, LG and Hyundai merged into the Hyundai-operated Hynix, which in 2003 despite subsidies hovers close to bankruptcy. In spatial terms, most leading DRAM producers have fabrication facilities in Asia, North America, and Europe, though Europe has the fewest.

Monitors based on CRTs are a declining industry because of the competition from FPDs (see the chapter by Murtha, Lenway, and Hart). Traditionally, CRT monitors run the gamut from being a high-quality monitor ($1,000) to a low-end monitor ($150), but, in general, they were a medium-value product that experience a medium-level of price erosion. There are no U.S. firms producing either CRTs or monitors. Japanese firms originally dominated the industry, although competitors from Korea and Taiwan have captured ever-greater market share and overcome the Japanese lead even in high-end monitors. This contrasts with televisions, where Japanese firms continue to dominate large-size television CRT production.

The geography of CRT monitor production differs from that of FPDs, in the sense that CRT components are produced globally, roughly mirroring the production of CRTs for televisions (see Kenney in this volume). During the two decades Asian firms have inexorably gained market share from Western firms. In 2001 Samsung was the largest monitor CRT producer in the world, while LG Electronics was number two. Samsung has factories in the United Kingdom, Brazil, Mexico, China, Korea, Malaysia, and in 2000 it announced that it would build a factory in India (Bloomberg 2000a). Though the factories are scattered throughout the world, the bulk of production is in Asia. More recently, the move to FPDs is decreasing monitor producion. For example, in 2001 one major competitor, Hitachi, announced that it would close its CRT monitor production facilities in Japan and Malaysia, preferring to concentrate upon FPDs (Reuters 2001). In general terms, it is safe to say that CRT production is being phased out in developed countries, while it is still growing in the developing nations, especially China.

Despite the Korean strength in monitor CRT production, Taiwanese firms and Taiwan are the center of monitor production. In 2000, Taiwanese firms shipped 59.6 million CRT monitors, which accounted for 53.7 percent of global CRT monitor shipments. However, the data indicate that monitor assembly has moved offshore from Taiwan (see Figure 5.1). One important factor was the desire by assemblers to reduce their monitor inventory. This is possible because the monitor is often delivered in a separate package. Immediately prior to final delivery, the shipment is integrated at a local delivery center operated by UPS or FedEx. For example, a PC ordered from Dell actually triggers two shipments: Dell's shipment of the PC and a monitor producer's shipment of the monitor. This eliminates the need for Dell to carry monitors in inventory and a redundant shipment of the monitor from the monitor factory to Dell's warehouse. However, to effectively undertake this strategy, the monitor assembler must be able to reliably fulfill Dell's order. If the monitor firm is importing the monitor from Asia, then it must carry sufficient inventory. To achieve proximity the Taiwanese monitor manufacturers opened factories in Northwest Mexico, where

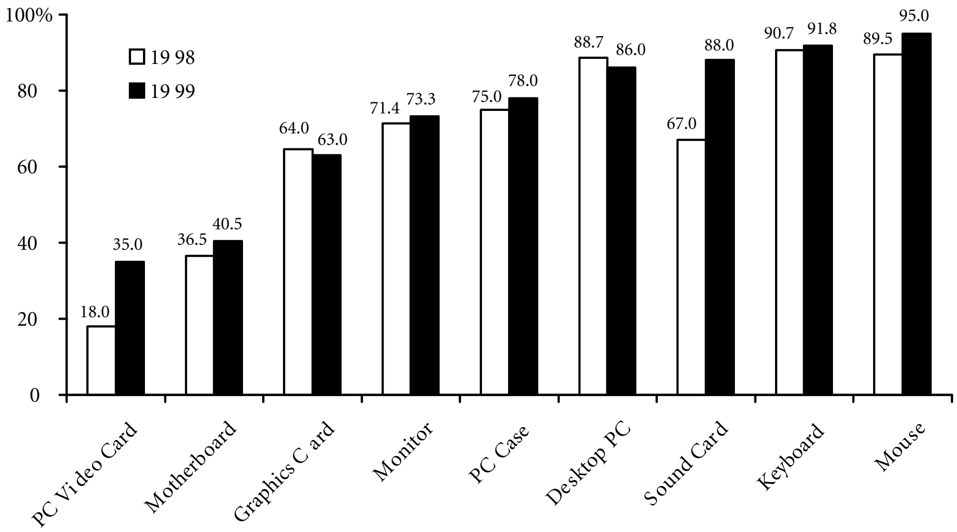

FIG. 5.1. Taiwan's IT Hardware Industry's Overseas Production, 1998 and 1999.
Source: ITIS Project, MIC/III, 1999.

Samsung, LG, and Mitsubishi built monitor CRT factories (Sony also has a monitor CRT plant in San Diego, though in 2002 its low-end monitor production was transferred to Asia). From 2000 onward, these factories came under severe pricing pressure because of the extremely low production costs in China. In 2001, Taiwanese monitor producers MAG and Acer closed plants in Mexicali, while Tatung never began production at a plant it had constructed in Tijuana in 1999. In general, CRT monitor production was under pricing pressure globally because of the cost advantages in China, which has been steadily increasing its global market share (*Electronic Engineering Times* 2001).

These four key components differ from MPUs and the OS in the sense that they are commodities, and, in general, it is difficult to extract significant profit unless the firm is the market leader—and even then continuing profitability is a struggle. In three areas, CRTs, FPDs, and DRAMs, north Asian firms are the global leaders. As McKendrick explains, it is only in HDDs where the U.S. firms have retained their leadership position, though Japanese and Korean firms continue to be competitors.

Secondary Components

A third tier consists of secondary components and revolve around other important semiconductors and their accompanying printed circuit boards. These components are the motherboard and its chipset, the multimedia chips, and sound and graphics cards, the communications chip and its card, and the BIOS chip. Taiwanese firms are extremely competitive in supplying these logic chips as well as the board-level implementations of these components. The chips are designed by a number of firms—some of which are Taiwanese, with most of the others being American. As Leachman and Leachman demonstrate, fabrication is then subcontracted to the Taiwanese semiconductor fabricators, TSMC or UMC, and yet another Taiwanese firm often operating a factory in China will both design and assemble the printed circuit board (PCB). While many of the processes that go into making a finished board are highly automated, there is still hand labor involved, including insertion of some chips into boards, machine tending, inspection, testing, packaging, and so forth (Barnes 1997). As Table 5.5 indicates, profitability is superior to commodities but does not compare to that of Microsoft and Intel. The most profitable components are the chipsets and motherboards, as shown by the profitability of VIA and Asustek, while the least profitable are likely the communications chips and adapter cards, as illustrated by Accton Technology.[14] Motherboard chipset design is done either in Taiwan (VIA, SIS, and ALI), or Silicon Valley (Intel). Graphics and sound chip design is done in Taiwan (SIS and RealTek), Canada (ATI), Silicon Valley (e.g., ESS Technologies, NVidia, and Cirrus Logic), and Singapore (Creative Technologies). Here, Taiwan has been able to move from the commodities described in the next section to these more sophisticated products. These firms often do their own design work, and, in many cases, sell their products under their own label. New sophisticated graphics chips and motherboard chipsets can provide good returns, but especially in graphics chips commodification is a constant threat, because the technology changes rapidly and, because of the PC's standardized interfaces, there is little protection against a superior chip. It is not unusual to see branded graphics cards that only a year previously might have sold for $300 to $400 each now retailing at between $20 and $30.

The motherboard and the core logic chips on the motherboard (most important among them being the one or two chips referred to as the motherboard chipset) implement the PC's main bus, which controls the exchange of electronic pulses (data) through the various parts of the system. Counter to the general logic of disintegrating the value chain, the chipset and motherboard are of such importance that Intel produces chipsets and since the mid-1990s began producing some motherboards. Constantly improving chipsets are necessary if the PC is to derive all of the benefit of new MPUs. Chipsets are not as profitable as MPUs, but Intel can use its chipsets to force the pace of technology adoption. In 2001, Intel controlled about 40 percent of the chipset market, a sufficient market share to be able to control the pace and direction of its evolution.

Motherboard production is far more strongly dominated by Taiwanese firms. In 2000, Taiwanese firms accounted for nearly 75 percent of total worldwide motherboard production (Wilcox 2001). The Taiwanese producers' motherboard commodity chain has increasingly become more geographically dispersed as Taiwanese firms have moved the assembly of basic boards to low-wage areas, mostly to China but also to Thailand and the Philippines. Of Taiwan's total motherboard production, 39.9 percent was produced "offshore" in 1996, accounting for 29.6 percent of worldwide production. By 2000, Taiwanese firms produced 84 percent of all motherboards, of which 48 percent were produced offshore, so offshore Taiwanese production was 42 percent of total global production (Taiwan Technology 2001). Intel accounted for most of the remaining production. The Taiwanese leader, Asustek, supplied about 50 percent of the Taiwanese production and also had the good profit margins that accrue to the leader. In 1996, motherboard production was quite globalized, but China is rapidly increasing its share of global production as factories in other parts of the world close.[15]

The logic chips on the other cards in a PC are designed in various countries, but particularly important design locations are Silicon Valley and Taiwan. These firms are less profitable than the chipset producer VIA and the motherboard producer Asustek. Wherever these chips are designed, almost invariably they are fabricated by either TSMC or UMC. Perhaps even more so than is the case with motherboards, these various boards are produced either in Taiwan or China. As in the case of motherboards, in response to severe price pressures production is being relocated from Taiwan to China.

Commodity Components

The most commodified components in the PC consist of power supplies, keyboards and other input devices, the case, cables and connectors, floppy disk drives, and so forth. With the possible exception of high-end keyboards and input devices, these are largely unchanging and experience minimal improvement in functionality. Because they experience little price erosion, they can be manufactured anywhere. The only significant trade-offs are between labor costs, material costs, and cargo container shipping costs. With little new design input, the vast majority of these components do not experience significant price erosion. There is one interesting twist, however: as the price of PCs decreases, these items will likely become a greater portion of the total cost, because most of the cost savings have already been wrung out.

The commodity component that does have some opportunities for design input and improvement that can increase profitability is input devices. For the most part this is in the after-market, where consumers wish to upgrade their keyboard, mouse, or gaming device. The two most significant firms in this field are Microsoft and Logitech. Microsoft's division selling input devices has been very profitable. The federal government's Microsoft antitrust case indicates that the peripheral's division benefited significantly from Microsoft's pressure on PC assemblers to use or, at least, offer Microsoft's peripherals as an option. Another significant input device firm is the Swiss firm Logitech, which commits 4.8 percent of its revenues to R&D and has relatively strong profits (see Table 5.5). Logitech competes on the basis of design and its strong marketing channels. Whereas Logitech operates its own factories in China, Microsoft simply outsources its production to Asian firms. There is also some production of input devices in Mexico by Taiwanese firms, but the vast majority of the mice, keyboards, and so forth are produced on an OEM basis for firms such as Compaq, Dell, and HP in low-wage locations in Asia, especially China, and then shipped in cargo containers to the United States.

The remaining components include computer cases (the proverbial beige box), cables, connectors, screws, fans, and miscellaneous other parts. These are commodities and experience little innovation or change. The production locations for these parts are difficult to trace, however; if they are small, almost invariably they are produced by Taiwanese firms in Asia. Computer cases are produced by Taiwanese firms in Taiwan or, more recently, China, though some of these Taiwanese firms have established Mexican factories to supply their U.S. customers.

The market for low-value, standardized components is largely supplied by Taiwanese firms that have lower cost structures than their Western or Japanese counterparts. The only barrier to entry is having industry standard quality and having the lowest price, resulting in intense pricing pressure and very low profit rates. Design, engineering, and greater scale can wring incremental costs out of these items, but the major cost savings have come from lowering labor costs. The question is whether, after moving production to China, even lower labor cost environments can be found.

Reflections

Two features of the PC determine the configuration of the PC industry. First, the architecture of the PC, which has allowed the development of an extreme version of modularity, has given rise to its vertically disintegrated value chain. Second, the rapid decline in value of its semiconductor and hard disk drive components emphasizes the importance of situating the final segment of the value chain in close proximity to the final consumer. For the PC assembler, controlling logistics is critical for commercial success. Few products experience the ravages of delay induced devaluation as palpably as the PC. Dell Computer's business model is based on managing and even benefiting from the technical speed of change in the PC value chain.

Global supplier chains in the PC industry use air freight for the high value-added items while using slower transportation to transport the lower value-added items. The PC and garment industries both suffer from having perishable products—in one case because of the exigencies of changing fashion, and in the other case because of the speed of the technical improvement of certain key components. Inventory of these key components is subject to a relentless destruction of value. Dell Computer's success is due to its logistics system and the BTO business model that allows it to manage the depreciation dynamic.

Most interestingly, there is little spatial clustering among PC assemblers, nor is there any significant clustering of supplier production activities close to PC assemblers. Dell is the exception, because it demands that suppliers have a warehouse within a twenty-minute commute of the assembly plant. However, the suppliers' production facilities can be located anywhere. This lack of clustering can be explained by the fact that the PC is a modular product with rigidly specified component interfaces with a very high degree of interchangeability. In effect, for desktop computers all of the knowledge necessary for assembly is already codified, and little tacit information is required for assembly. This means that the assembler-supplier relationship can be entirely market-based.

The only important global cluster is located in Taiwan, where the assemblers are close to each other and to component suppliers. As we have shown, many of the components used around the world are sourced from these Taiwanese firms; however, they never controlled the key components including the operating system, the microprocessor, and the HDD. Therefore, despite the considerable success that Taiwanese firms have experienced, it has been difficult for them to capture high levels of value added. In both spatial and organizational terms, advantage has been captured by two firms: Microsoft and Intel garnered a disproportionate share of the value chains profit.[16] Having inherited the crown jewels of a near monopoly position from IBM, each had greater profit margins than any of the other firms in the chain and, though no comprehensive accounting is available, probably captured greater profits than all the assemblers combined. Thus power is concentrated in these two standard-bearers. U.S. assemblers dominate global sales of the world's PCs—a commodity with low profit margin—despite the fact that Taiwanese firms produce approximately half the total supply. U.S. assemblers have significant advantages. First, they have enormous volumes that permit them to extract the greatest volume discounts from suppliers. Second, and probably most important, they benefit from being in the world's largest and most advanced market, where new "killer" applications first emerge and become standardized—for example, the general use of the Internet (Kenney 2003), or using PCs as MP3 burners. U.S. firms are in a position to learn from the market and have tomorrow's globally desirable products today. This "proximity to the market" is as important as production efficiency, as generations of Asian producers trying to enter the U.S. market have discovered.

Globalization in the PC industry has transferred much of the manufacturing of PCs and their components to Taiwan and now China. However, this has not been a zero-sum game for the United States. Microsoft, Intel, and, increasingly, Dell have been the greatest beneficiaries of the PC industry.

Notes

The authors thank Gary Fields for valuable suggestions and comments.

1. This paper refers only to PCs using the Microsoft operating system and an x86 microprocessor, which account for 95 percent of the world's PCs.

2. In terms of the software standards-based interaction of the various components, notebook computers are interesting, because they are, for all intents and purposes, as modular as desktop PCs. However, because of the tight tolerances arising from attempts to decrease the weight and dimensions of the machine, it is difficult to fully black box the components. This frustrates modularity by creating physical interdependencies (Baldwin and Clark 2000). So, for example, the heat given off by the microprocessor is not easily vented to the environment; this affects other components, thereby creating an interdependency.

3. We thank Gary Fields for pointing out these attributes of Dell's overseas operations. See also Fields (2003).

4. For the modern electronics industry, physical proximity is not always as important as what might be called "hyperspatial proximity"—that is, easy access to transportation nodes. Thus, in Mexico for example, Guadalajara has a distinct advantage over Tijuana in large-scale electronics contract manufacture. In the United States, Tennessee became a center of PC assembly, because of the large UPS hub in Nashville and the Federal Express hub in Memphis. In Mexico, even though Tijuana is closer to many U.S. markets, it lacks the air cargo transport infrastructure capabilities that Guadalajara has. As Kenney (this volume) shows, northern Baja California has a distinct advantage in televisions, a large product characterized by a slower rate of technological change that can be efficiently shipped by road or rail.

5. IBM had retained the BIOS chip as a lever of control, however Compaq was able to reverse engineer it. Once Compaq had done this, others did also, and the final lock was broken, enabling other firms to enter. Without recognizing it at the time, IBM gave Microsoft and, to a lesser degree, Intel the control that it had exerted in other classes of computers.

6. For a further discussion of the control of the Wintel standard, see Borrus and Zysman (1997).

7. We thank Gary Fields for pointing this out. For further discussion, see Fields (2003).

8. Gateway has recently seen sales slump as its core customers, U.S. consumers, have lengthened their upgrade cycle.

9. In the first quarter of 2003, the largest branded assembler, Dell, had captured 30.7

percent of the U.S. market, an increase from 20.7 percent in the same quarter a year earlier (Gartner Inc. 2003).

10. Dell's effort to gain market share created an extremely difficult pricing climate in 2001. The local retail assemblers are under severe pressure, because the largest manufacturers are able to secure larger discounts from suppliers and during the price war are passing these discounts on to consumers.

11. For a detailed discussion of the Dell model, see Curry and Kenney (1999) and Fields (2003).

12. For the sake of clarity and brevity we limited this discussion to common desktop PC components. Technologies usually associated with notebook PCs such as PCMIA cards, FPDs, and peripheral PC components such as printers, speaker systems, and so forth, are not considered.

13. It should be noted here that Transmeta's microprocessor products, while compatible with Intel/AMD chips in running Microsoft software, are predicated on an entirely different technology. Unlike AMD, which could be characterized as essentially a quasi-cloner of Intel chips and as such is a direct competitor to Intel, at this juncture at least, it seems that Transmeta may end up as a niche competitor in the low-power device market.

14. The reason for Accton's relatively low profitability is that most desktop PCs use Ethernet adapter cards. The chip technology for Ethernet is nearly twenty years old, and there is little new innovation.

15. The data in Table 5.3 is based on the author's 1996 survey covering roughly 80 percent of mainboard producers worldwide.

16. See Borrus and Zysman (1997).