From Partial to Systemic Globalization: International Production Networks in the Electronics Industry

Dieter Ernst
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Dieter Ernst, Ph.D., is a Senior Research Fellow at BRIE. He is currently a professor of International Management at Copenhagen Business School, Denmark. Before joining BRIE, Dr. Ernst had been a senior advisor at the OECD Development Centre (Paris). For over two decades, Dr. Ernst has written about technology and international competition in various industries and implications for firms' strategies and government policies.

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THE ISSUE: OPENING THE BLACKBOX OF "GLOBALIZATION"

Far-reaching changes are currently occurring in the organization and location of the production of industrial goods and services, changes which are bound to have important implications for the welfare, the development potential, and the competitive position of different countries and regions. As competition cuts across national and sectoral boundaries and becomes increasingly global, firms everywhere are forced to shift from exports to international production. Today, dominance in a domestic market--even one as large as the U.S.--is no longer enough. Mutual raiding of established customer and supply bases has become an established business practice, with the result that firms are now forced to compete simultaneously in all major markets, notably in Europe, North America and Asia.

This has led to a rapid expansion of international production: new production sites have been added at a breath-taking speed outside the industrial heartlands of Europe, North America and Japan. Since the mid-1980's, international production has grown considerably faster than international trade. Today, the sales of foreign affiliates of TNCs far outpace exports as the principal vehicle to deliver goods and services to foreign markets. The expansion of international production is likely to continue.[1]

Yet, quantitative expansion is only part of the story. Of equal importance are qualitative changes: a shift from partial to systemic forms of globalization. In order to cope with the increasingly demanding requirements of global competition, companies are forced to integrate their erstwhile stand-alone operations in individual host countries into increasingly complex international production networks. Companies break down the value chain into discrete functions, and locate them wherever they can be carried out most effectively and where they are needed to facilitate the penetration of important growth markets.

Reduction of transaction costs is one important motivation. Of equal importance are access to clusters of specialized capabilities and contested growth markets, and the need to speed up response time to technological change and to changing market requirements.

This raises an intriguing question: As the pace of globalization accelerates and as this deepens the functional integration between previously separate national production systems, how will this affect firm strategies? And, more specifically, will globalization increase rather than decrease the choices that companies have in organizing their worldwide production activities? In

[1] 1996 World Investment Report, UNCTAD, Geneva.

order to answer this question, we need to open the blackbox of "globalization." In other words, we need to inquire why firms are forced to shift from exports to international production, what factors shape the location and organization of such activities, and why firms differ in how they approach international production.

This study is an attempt to provide a conceptual framework for addressing this research agenda. The focus is on the electronics industry which has been at the forefront of globalization; indeed, the electronics industry's reliance on international markets and production is unrivaled by any other industry, as is its exposure to international production networks. The industry also reflects quite well the increasingly complex requirements of global competition. As this study is part of the Sloan Foundation project on "The Globalization of the Data Storage Industry," I will try to include, wherever possible, illustrative examples from this particular sector of the electronics industry.

The analysis proceeds in four steps. In chapter I, I analyze how the increasingly demanding requirements of global competition are reshaping the entry barriers and the structure of the electronics industry. I also identify some distinctive competitive challenges that set the hard disk drive industry apart from the rest of the electronics industry.

In chapter II, I analyze how this has led to a shift from partial to systemic forms of globalization and the spread of international production networks. I show that international production networks are more than "governance structures for economizing on transaction costs."[2] Of equal importance are the search for clusters of specialized capabilities and access to contested growth markets. The focus on capabilities is consistent with the evolutionary theory of the firm which argues that competition today centers around a firm's ability to build capabilities quicker and at less cost than its competitors.[3] The focus on market penetration is consistent with Dunning's eclectic FDI theory, which considers spatial variations in the size and composition of markets as a critical location-specific factor.[4]

[2] McKendrick, Stout and Pich [1994] argue that a focus on transaction costs needs to be complemented with an analysis of network learning. For similar arguments, see Ciborra [1991]. See also the interesting research agenda described in Nahapiet [1996].
[3] Important contributions include Nelson and Winter [1982], Winter [1982], Dosi, et. al. [1988], and Kogut and Zander [1993].
[4] Dunning [1981], p. 9 passim.

In the remaining two chapters, I analyze two main features of systemic globalization: geographic dispersion and concentration, and the increasing complexity of value chain activities that move abroad.

Chapter III deals with the first of these issues. It shows that electronics firms have pursued a variety of geographic dispersion strategies, and documents the new patterns of specialization that are emerging in various sectors of the electronics industry.

Finally, Chapter IV analyzes some important aspects of the increasing complexity of international production: (1) new products are produced overseas much earlier than predicted by the product life cycle (PLC) theory; (2) the scope of international production has been substantially broadened and now covers all stages of the value chain, including some high value-added support functions; (3) outsourcing has increased in importance, and now covers a variety of high value-added support functions; and (4) systemic rationalization now cuts across national borders and covers a variety of cross-border linkages. To the degree that proximity advantages can be replicated abroad, these factors have further expanded the internationalization of the value chain. In other words, once manufacturing moves abroad, there is a strong tendency for a concomitant migration of key support functions.

Chapter I: The Dynamics of Global Competition in the Electronics Industry

1. Strategic Games and Entry Barriers

More than in any other industry, competition in the electronics industry today cuts across national and sectoral boundaries. In order to compete in this industry, a firm must be able to internalize, on a global scale, specialized assets and capabilities, including technological knowledge, organizational competence, finance, production experience, supplier and customer networks and market intelligence. These capabilities are important because they can lead to the timely development and effective commercialization of a wide variety of electronics goods and services. Of critical importance is that the firm can build these capabilities quicker and at less cost than its competitors.[5]

Due to pervasive globalization pressures, fundamental changes have occurred in competitive behavior and how firms create or acquire these capabilities. No firm, not even a dominant market leader, can generate all these different capabilities internally, let alone deploy

[5] Winter [1982], Prahalad and Hamel [1990], and Kogut and Zander [1993].

them on a global scale. This necessitates a shift from individual to increasingly collective forms of competition, "... from the legal entity known as the firm to the contractual network of firms tied together by mutual long-term interest."[6] Competition is thus primarily shaped by "strategic games" among the leading companies or coalitions of firms which position themselves so as to discourage or dictate the actions and responses of their current and potential competitors.[7]

Such games are played on different levels, with cooperation often going hand in hand with intense competition. For instance, competitors can cooperate on basic support services (such as R&D and standards) and intermediate inputs (such as materials and components), while maintaining keen competition at the final product stage. Or they may join forces to create a variety of entry deterrence strategies against possible new entrants. Of equal importance are joint attempts to restrict technology leakages and to control the range of products and services that could act as superior substitutes.

Governments also play an important role in such games. In most sectors of the electronics industry, a variety of regulatory barriers restrict access to new technologies, product standards and markets. This reflects the growing "politicization"[8] of competition in an industry which is widely claimed to be of strategic importance.[9]

An impressive arsenal of regulatory barriers exists today in the electronics industry.[10] These barriers include: (1) restrictions on market access, whether through discriminatory access to government procurement markets or through market share quotas and "market reservation" schemes; (2) restrictions on the establishment of firms in a particular activity through, for instance, statutory monopolies, investment licensing, or restrictions on FDI; (3) regulations concerning standards for product design, quality, and reliability, and interface and connectivity requirements; (4) restrictions on access to scientific and technological knowledge and particular types of human resources, including restrictive intellectual property rights, technology export controls, and restrictions on the mobility of engineers and scientists; (5) limitations on access to key components; (6) restrictions on pricing behavior and the establishment of distribution

[6] Stopford [1995], p. 21.
[7] For a theoretical foundation see, inter alia, Jacquemin [1987].
[8] Gilpin [1988], p. 164.
[9] For a useful debate on the concept of "strategic industries," see the papers by Sylvia Ostry, Luc Soete, David Teece, and M. Yoshitomi, presented to the OECD Forum for the Future Conference on "Support Policies for Strategic Industries: Systemic Risks and Emerging Issues," Paris, October 30, 1990.
[10] For details, see Ernst and O'Connor [1992], chp. 1, p. 40-43.

channels; and (7) restrictions concerning the financial behavior of firms, especially with regard to discriminatory fiscal treatment and restrictions on profit repatriation.

In short, competition in the electronics industry is based on strategic interaction between firms and governments. It centers on market positions and on the definition of the rules of the game, where technological and organizational innovations, entry deterrence strategies, and regulatory barriers are used as important weapons. Creating and destroying entry barriers thus has become the essence of competition in this industry. What separates the electronics industry from other industries, however, is the intensity, spread, and variety of such entry barriers, their complex dynamics and their increasingly systemic nature. As R&D and capital intensity are high and rapidly increasing, entry barriers into the electronics industry in general are well above the industry average.[11]

As usual, the average hides the essence of the story. Once we disaggregate by product groups and market segments, we find a complex picture. The electronics industry has a reputation for a historically unprecedented rate of technological progress.[12] Rapid technical change, however, has acted as a "double-edged sword."[13] In some sectors, trajectory-disrupting innovations have dismantled entrenched entry barriers and have acted as a powerful equalizer by eroding the competitive advantages of erstwhile market leaders. At the same time, however, rapid technical change has produced very steep entry barriers in sectors (for example, microprocessors) where its implementation requires huge and rising R&D and investment outlays and where economies of scale, scope, and learning are of critical importance.[14]

Let us take a closer look at the nature of entry barriers in the electronics industry.[15] The analysis of barriers to entry has focused primarily on the impact of economies of scale in industrial manufacturing. As Bain has shown in his pioneering work,[16] scale economies can constrain the entry of new firms if the minimum efficient scale of operation is high relative to the size and growth rate of the market, and if dynamic economies of scale or learning economies

[11] Howell et. al. [1988].
[12] For indicators, see Flamm [1990], p. 4 passim for the computer industry, and Gilder [1988] for the semiconductor industry.
[13] Ernst and O'Connor [1989], chp. 1, p. 21 passim.
[14] That technical change acts as a double-edged sword is consistent with John Stopford's observation that global competition is "shaped by forces that have opposite effects simultaneously" See Stopford [1996], p. 14.
[15] The following is based on the author's earlier analysis in Ernst and O'Connor [1992], chp. 1.
[16] Bain [1956, 1966].

result in unit cost reduction with cumulative production experience.[17] Under such conditions, temporary monopoly positions of firms can be quite persistent. The same applies to the "technology gap trade" to which monopoly leads.[18] Case studies on the semiconductor and computer industries have shown that as long as initial innovators are able to generate a continuous flow of process and product innovations, the competitive efforts of would-be imitators can be repelled.[19] It is widely assumed that this is largely due to the important role which threshold barriers and learning economies play in both industries.

Yet, scale economies are only part of the story. A much broader view is required in order to capture the great variety of entry barriers in the electronics industry and possible interactions between them. Such a broader concept is also necessary to understand how entry barriers vary over time and space and across different product groups and market segments. Four types of entry barriers[20] are essential for an understanding of the global dynamics of competition in the electronics industry: (1) production-related scale economies, including learning economies, threshold barriers and economies of scope; (2) barriers related to intangible investments required for developing the knowledge and competence base as much as complementary support services; (3) barriers to entry and exit of supplier networks, such as subcontracting and OEM (original equipment manufacturing) arrangements; and (4) barriers related to sales, marketing (especially with regard to distribution channels and the creation of global brand images), and after-sales services.

Elsewhere, I have provided a detailed analysis of the development of each of these different types of entry barriers in the electronics industry.[21] The main findings can be summarized as follows. Technical change and changes in demand continuously create new products and markets and thereby create new entry possibilities. Thus, entry barriers have declined for a number of product groups and market segments. Simultaneously, however, entry barriers have increased for those stages of the value chain which are currently of critical importance for competitive success. Production-related scale economies continue to matter. But the epicenter of competition has shifted to R&D and other forms of intangible investment that

[17] For an analysis of learning economies, see Hayes and Wheelwright [1984], chp. 8.
[18] Posner [1961].
[19] Scibberas [1977], Golding [1971], Ernst [1983], Dosi [1984], Borrus [1988], and Ferguson [1990].
[20] Important contributions to the concept of entry barriers include Bain [1956, 1959, 1966], Scherer [1980], Baumol et. al. [1982], Ergas [1987], Howell et. al. [1988], Perez and Soete [1988], Baumol [1992], and Greenaway [1992].
[21] Ernst and O'Connor [1992], chp. 1, p. 26-45.

are necessary to enhance a firm's speed of response to changes in technology, markets and regulations. In short, what really matters are the substantial investments required in the formation of a firm's technological and organizational capabilities.[22]

2. Changing Competitive Requirements

These changes in the nature and the dynamics of entry barriers are due to quite fundamental changes in the competitive requirements. Traditionally, two types of competitive strategies could be distinguished in the electronics industry. For consumer electronics and electronic components, competition used to center primarily on cost reduction and judicious pricing. Non-price competition was largely restricted to a few high value-added market niches. In the computer industry, on the other hand, the focus of competition has been on product differentiation, based on proprietary computer designs and market segmentation. In short, it was possible to neatly separate patterns of competition in the electronics industry by sector, product group, and market segment.

Today, this is no longer the case. In almost every sector of the industry, firms have to cope with much more complex requirements, where price and non-price forms of competition are closely intertwined. In contrast to a widespread misconception that electronics products are all differentiated products, this industry covers an extremely broad variety of products that face very different patterns of demand. Some electronic products are homogeneous products in the purest sense, while others are highly differentiated products that require very intense and continuous interaction between producers and users.

The distinction between homogeneous and differentiated products, however, has decreased. Most electronic products have become "high-tech commodities": they combine the characteristics of mass production with extremely short product cycles and periodic trajectory-disrupting innovations. As a result, cost competition must be combined with product differentiation and speed-to-market. Mass production implies large investment thresholds that are necessary to reap economies of scale. Short product cycles imply the rapid depreciation of plants, equipment, and R&D. Only those companies who are able to get the right product at the right time to the highest volume segment of the market can survive. Entering a new market right

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[22] For an interesting analysis of some institutional barriers to the development of such capabilities in American companies, see Baldwin and Clark [1994].

on time can provide substantial profits. Being late is a disaster which quite frequently may force a company out of business. Probably of greatest importance, however, is the increasing uncertainty that results from periodic trajectory-disrupting innovations: established leadership positions can no longer be taken for granted, and the target of competition becomes fuzzy and can change at any time.

These changes in the economics of competition have had far-reaching implications for market structures. Take, for example, the computer industry. The development of the computer and the invention of the transistor allowed the U.S. to establish a firm worldwide leadership in the electronics industry during the late 1940's. Originally, this leadership was personified by two companies, IBM for mainframe computers, and AT&T Bell Labs for microelectronics. As outlined by Schumpter, competition in the industry was traditionally based on successful R&D investments that created temporary monopolies.[23] The focus was on product differentiation, based on proprietary computer designs and market segmentation. As Flamm has convincingly demonstrated, "...[a] process of technological differentiation, with new competitors defining new market niches, has been central to the way in which competition has evolved."[24] Competition in the computer industry was thus characterized by a basic paradox: despite IBM's early leadership and the oligopolistic nature of competition, there have always been possibilities for latecomers to enter the fray by means of product differentiation and market segmentation strategies.

IBM's dominance reached its peak in the mid-1970's. Competition in the computer industry had then settled into a fairly stable pattern, "... with IBM dominating the mainstream of business computing and several well-established but smaller firms nibbling at the margins in emerging markets not covered by the umbrella of IBM's general purpose architecture."[25] Since then, dramatic changes have occurred in the structure of the industry. IBM's fall from its position as an industry hegemon is common knowledge. What is less well known is that IBM's decline is representative of a much broader development--the pervasive destabilization of established market structures. This has happened as a result of the continuous down-sizing of computer systems, which has made them increasingly interchangeable, and some progress towards open,

[23] For the original version of this argument, see Schumpeter [1912] ("Theorie der wirtschaftlichen Entwicklung"). This initial version of the work was later popularized in the widely quoted book Capitalism, Socialism and Democracy. See Schumpeter [1942].
[24] Flamm [1988], p. 204.
[25] Flamm [1988], p. 235.

non-proprietary computer systems.[26] Across the board, none of the leading contenders is strong enough to turn the tables in his own favor. In addition, the distinction between the different segments of this industry has become blurred and nobody's established customer and supply base is immune to raiders from outside. The result is that, for each participant, the scope of competition becomes much broader and requires an increasingly complex set of capabilities. Furthermore, the rules of competition have become much more unpredictable.

Under such conditions, competing in the electronics industry has become a hazardous game. I will discuss in chapter II how electronics firms have been forced to adapt their organization of production in order to cope with such an increase in complexity and risks. We will see that the main response has been a shift from partial to systemic forms of globalization. Let us first, however, briefly consider some key features of competition in the hard disk drive (HDD) industry and ask to what degree this industry fits the general pattern that I have described so far.

3. Competitive Challenges in the Hard Disk Drive Industry

Hard disk drives (HDDs) are the workhorses of mass storage and are widely used in computers of all sizes, from the most powerful super-computers to the tiniest laptop PCs. The world market for HDDs today is almost $26 billion.[27] By any standard, this is a large and important sector of the electronics industry.

This industry also provides an excellent example of the increasingly complex competitive requirements that result from the globalization of competition. HDDs are archetypal "high-tech commodities": economies of scale are crucial for most stages of the value chain, and this goes hand in hand with very short product cycles and a hectic pace of technical change. In addition to scale economies (3.1.), this industry is also characterized by very complex capability requirements (3.2.) and a high degree of volatility (3.3.).

There are, however, some important factors which differentiate the HDD industry from other sectors of the electronics industry. We will see that, in terms of the sources of volatility, demand fluctuations and trajectory-disrupting innovations have played a less important role than for final-use products like PCs and consumer electronics. A second important hallmark of this

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[26] For an analysis, see Ernst and O'Connor, 1992, chp. 2, p. 77-83.
[27] <u>1995 DISK/TREND Report. Rigid Disk Drives</u>, DISK/TREND, Inc., Mountain View, CA (October 1995), p. 9.

industry is the incredibly demanding requirements of its supply chain logistics: HDD assembly is heavily dependent on a large number of high-precision components, and their sources are typically spread across different time zones and continents. Compared to the extremely demanding requirements in the HDD industry, procurement requirements for PC assembly and consumer electronics are much more mundane.

Despite a peculiar set of industry features, the competitive requirements in the HDD industry are not much different from the rest of the electronics industry: intense price competition needs to be combined with product differentiation, while continuous price wars have drastically reduced profit margins. Addressing these three goals simultaneously comes close to a squaring of the circle. Doing so, however, almost inevitably gives rise to high entry barriers and to an increasing degree of concentration (3.4.).

3.1. Scale Economies

Scale economies are of critical importance in the HDD industry, and continue to increase rapidly. In final assembly, economies of scale are largely attributable to costly overhead investments like the construction of "clean room" environments and expensive test equipment. Huge investments are also required in precision tools, moulds, and dies that are required to make the various high-precision components and parts that go into a drive. For some of these components, like thin-film or MR recording heads, minimum economies of scale are as high as those required for integrated circuits.

Let us look at a few indicators that demonstrate how important mass production is for this industry. Seagate, one of the industry leaders, owes its success to a consistent focus on high-volume, low-cost manufacturing, backed up by an early shift of production to East Asia. Typically, Seagate waited until a market opened before entering with volume manufacturing to dominate the particular market segment. With Seagate's mass production strategy providing large cost advantages, other companies were ultimately left behind.[28] Today, out of Seagate's 5.6 million sq-ft worldwide manufacturing capacity, more than 60 percent (3.4 million sq.-ft.) is in Asia.[29] This Asian production capacity is concentrated in three Asian mega-plants, with each

[28] In essence, this strategy copies the concept of "capacity wars" that major Japanese electronics manufacturers had developed earlier on for consumer electronics and for computer memories. The idea is to drive up investment thresholds as quickly as possible so that smaller competitors with less financial clout can no longer compete.
[29] Figures are from the Seagate profile, compiled by Allen Hicken, 11/6/1995.

plant responsible for roughly one third of capacity (i.e. slightly more than 1 million sq.-ft.). By any standard, these are very large production facilities that come close to the orders of magnitude that are typical today for the consumer electronics and semiconductor industries.[30]

Minimum economies of scale in the HDD industry apparently have grown very rapidly over time. In 1989, an annual production capacity of between 900,000 and 1 million units[31] was regarded as economic scale.[32] Seagate's Bangkok production facility, for example, had a registered annual production capacity of 940,000 units in 1989. In that same year, Matsushita Kotobuki's new production line for 3.5" drives in Japan was designed to produce 1.2 million drives per annum, making it one of the largest facilities worldwide.[33] Based on a regression analysis which measures the factors that drive differences in the total cost per unit for each major disk drive manufacturer for the period 1984-1992, Christensen (1994, p.18) concludes that "...the minimum efficient scale in the disk drive assembly business is about 4 million units (per annum)."

Since then, a dramatic increase has occurred in minimum scale. This reflects the fact that, with almost $26 billion worldwide sales revenues in 1995, the HDD industry has become a major industry. Capacity requirements in the industry are driven by a very rapid growth of demand; worldwide unit shipments increased by 35 percent in 1994, almost 26 percent in 1995, and are projected to increase by around 18 percent in 1996. To demonstrate the increase of economic scale, let us look at 1996 capacity figures reported by Maxtor, a U.S.-based HDD producer which is now wholly owned by Hyundai Electronics Industries, an affiliate of Korea's powerful Hyundai group. For its main plant in Singapore, Maxtor reports a capacity of 4 million drives, but this capacity is not per year, but just per quarter. In other words, annual capacity at this plant now is around 16 million units. Similar capacity levels are reported for Maxtor's new facility in Dalian, China.[34] , i.e. 16 milion units per year.

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[30] An analysis of the minimum economies of scale for various electronics sectors can be found in Ernst and O'Connor [1992], chp. 4, and Ernst [1991].

[31] The basic unit for counting disk drive shipments are spindles or spindle disk assemblies. A spindle disk assembly consists of the disk drive mechanism required to utilize a single disk of disk stack.

[32] Ernst and O'Connor [1992], p. 194.

[33] Note that Matsushita Kotobuki has been a contract manufacturer for Quantum Corp., the third largest vendor of HDDs, since 1984.

[34] COMLINE Daily News Service From Korea, March 6, 1996.

3.2. Complex Capability Requirements

This industry is also characterized by a breakneck speed of technical change: areal density, i.e. the amount of information that can be stored on a given area of magnetic disk surface, is increasing at about 60 percent a year.[35] At the same time, the speed of access to data is rapidly increasing in importance. In order to cope with both these requirements, HDD firms must be able to tap into scientific knowledge across a broad front, covering areas such as magnetics, coding, and electronics. HDD firms must also master a variety of very demanding technological capabilities.

Hard disk drives (HDDs) are high-precision machines that contain and rotate rigid disks on which data is magnetically recorded, and control the flow of information to and from these disks. HDDs require a variety of high precision engineering capabilities, for instance the production of miniature motors able to work under extremely demanding tolerances. This industry also requires the mastery of incredibly complex process technologies that are used for coating disks with very thin films of magnetic materials (the so-called deposition technique) and for producing specialized integrated circuits (ICs). In addition to some of the most sophisticated component manufacturing technologies, the final assembly of HDDs requires leading-edge automation techniques, including surface-mount technology.

Yet, while manufacturing matters, it is only part of the story. Competitive success in this industry also crucially depends on the capacity to develop innovative architectural designs that can provide cost-effective solutions to the manifold trade-offs that exist between size, storage capacity and access time of HDDs. Finally, leading-edge software capabilities are an equally important prerequisite for developing a viable HDD product. Indeed, both architectural design and software capabilities have been of crucial importance as instruments for product development and differentiation strategies.[36]

An additional complicating feature is that product cycles in this industry keep shrinking. On average, a new product generation is introduced every 9 to 12 months, and for some products the cycle can be as short as six months.[37] This leads to a rapid depreciation of plants, equipment, and R&D. Like semiconductors, the HDD industry thus falls prey to a "scissors effect" between

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[35] 1995 DISK/TREND Report. Rigid Disk Drives, DISK/TREND, Inc., Mountain View, CA (October 1995), p. 6.
[36] For an excellent analysis of the role that architectural design plays in this industry relative to component innovations, see Christensen [1993].
[37] More on the dramatic shortening of product cycles, see section I. 3.3. (iii).

rapidly increasing fixed capital costs and an accelerated depreciation of its assets.[38] The result is that speed-to-market and economies of scale are of critical importance. The need to combine size and speed implies that a firm must be able to ramp up production quickly to competitive yields and quality. This requires close interaction between design, proto-typing, volume manufacturing and marketing which, as we will see later, has important implications for the organization of international production.

Firms can reduce this complexity by pursuing a selective approach to the use of new technology. The main objective of innovation management is to avoid the unnecessary use of difficult, untested and hence costly technologies and to keep products as easy to make as possible. Take, for instance, recording head technology. MR heads, the current leading-edge technology, are potentially far superior relative to earlier technologies, including the current "best practice" thin film technology. However, as one industry participant noted, "MR heads are the most difficult technology--this industry has ever swallowed--difficult to design and to manufacture."[39] In order to implement this technology, fundamental changes are required in all aspects of HDD design, including head, disk, motor, and read-and-servo channels. The result is that most firms will only use MR heads for high-end applications required for work stations, mainframes, and servers. For desktop PCs, cost and time-to-market are crucial; it would thus almost be suicidal to try to implement an immature technology like MR heads.

In order to cope with this perplexing array of technologies, firms need to invest huge amounts in R&D, human resources, and capabilities. Yet, low margins prevent HDD firms from developing all of these capabilities in-house. HDD firms thus need to have continuous access to external suppliers and support industries that possess some of these capabilities. The result is that HDD firms are faced with very high costs of complex procurement logistics. With the industry characterized by heavy periodic shortages of key components, such procurement costs are likely to increase even further.

3.3. Volatility

A third important characteristic of the HDD industry is the prevalence of excessive boom-and-bust cycles. These cycles are due to a combination of three factors: (i) periodic spurts

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[38] For an early analysis of the scissors effect in the semiconductor industry, see Ernst, 1983, chp. 1.

[39] Ken Wing, executive vice president of R&D and reliability at JTS Corp, (an innovative start-up company based in San Jose,CA), quoted in *Electronics Business Today*, February 1996, p. 43-44.

of very rapid capacity expansion; (ii) a complex supply chain that leads to periodic shortages in key components; and (iii) highly volatile demand patterns.

(i) Spurts of rapid capacity expansion

Spurts of capacity expansion result from the importance of speed-to-market. Each time that a new product generation is introduced, HDD firms engage in a frantic race to become the first supplier: " If you're early to market there's a reward for that. You get gross margin, you get a lot of customer action. If you're late, you've missed it. There's no recovery from that."[40] HDD producers thus have all become masters in ramping-up production at short notice. The result is a built-in tendency for an overshooting of investment relative to demand growth. This has a paradoxical consequence. As mismatches between demand and supply occur periodically, the capacity to exit rapidly becomes as important as the capacity for rapid capacity expansion. Fast ramping-up and ramping-down hang together and require an incredibly short response time to changes in both markets and technology.

(ii) A complex supply chain

In terms of its logistical requirements, the HDD industry is probably the most demanding sector in the electronics industry. The industry requires a wide variety of high-precision components and sub-assemblies, and procurement involves a variety of sources that are spread over different time zones and continents. Such global supply chains are prone to frequent disruptions. Suppliers, for instance, can cause such disruptions through late delivery or through the delivery of defective materials. Of equal importance are periodic supply shortages for key components such as heads, media, integrated circuits, and precision motors. Geographic distance often magnifies the impact of such disruptions.[41] This leads to another paradox. While HDD firms excel in the rapid ramp-up of the final assembly lines, disruptions in the supply chain can easily thwart this achievement; if everything else is in place, but one tiny component is missing, all the efforts to ramp up production in time have been in vain.

Quantum, for example, relies heavily on outside vendors for most of its key components. In a recent filing with the U.S. Securities and Exchange Commission, the company freely admits that "... limited availability of certain key components has constrained the Company's revenue growth. There can be no assurance that similar shortages will not recur in the future, and the

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[40] William Roach, executive vice president for worldwide sales at Quantum Corp., quoted in *Electronics Business*

[41] The role of proximity for the organization of international production is discussed below in chp. IV.

Company's inability to obtain essential components or to qualify additional sources as necessary, if prolonged, could have a material effect on the Company's results of operations."[42] In order to reduce this threat, Quantum has acquired DEC's MR head division, hoping that this would "... drive our costs down and make sure that we [have] available high technology components...[when we need them]."[43] So far, however, doubts remain whether this approach will work. After all, Quantum's corporate culture has been shaped by a long tradition of heavy outsourcing which is difficult to change at short notice.[44]

Another example, Maxtor, illustrates how deadly a reliance on outsourcing can be. Maxtor, which used to be one of the leading U.S. suppliers of HDDs, experienced a dramatic fall in market share and was ultimately acquired by the Korean Hyundai group in 1995. Maxtors main weakness was a lack of strong in-house circuit design expertise.[45] In a recent 10K report, Maxtor explained how two serious component supply problems contributed to its decline: "The Company is experiencing a shortage of media. The shortage is anticipated to continue at least through [the second calendar quarter of 1996]."[46] Maxtor also faced a serious shortage for specialized input/output ICs that link disk and tape drives to computers: "...the Company expects a shortfall of about 1.1 million chips from Milpitas-based Adaptec Inc during the first three months of 1996...The Company has negotiated a payment of $1.4 million to Adaptec to secure 500,000 units to cover the shortfall, and an extra $1.5 million will be paid for the other 600,000."

(iii) Volatile demand patterns

Compared to end-user industries like the PC industry or consumer electronics, demand-related volatility factors are probably less important for the HDD industry. Yet, they still matter and, in some cases, may even be of critical importance.

The main market for HDDs is the computer industry.[47] As suppliers of an intermediate input to the computer industry, HDD firms compete for design-ins by computer companies.

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[42] Form 10-K Quantum Corp., Fiscal Year Ending March 31, 1995.
[43] Electronics Business Asia, interview with William Miller, ex-chairman and CEO of Quantum Corp., who had masterminded this acquisition.
[44] Since 1984, Quantum has heavily relied on contract manufacturing (from Matsushita Kotobuki) and outsourcing of components, which is "long" by the standards of this fast-moving industry. For a detailed analysis of Quantums' outsourcing strategy, see chp. IV below.
[45] Christensen and Rosenbloom [1995].
[46] Form 10-K, Maxtor Corp., fiscal year 1995.
[47] Some observers expect this to change. IDC, for instance, argues that as quick access to data becomes critical, the supply of storage devices that can record data for later retrieval and use will become an increasingly important industry on its own. IDC predicts that, by the year 2000, the data storage industry will "far outstrip" the HDD industry that caters to the needs of computer companies. See A. Choi, "Storage Devices Take Spotlight in Computer

Computer companies thus exert a considerable influence on the product mix, the product cycle, and the pricing strategies of HDD vendors. Decisions on the product mix are shaped by the increasing storage requirements of computers and their applications. Annual increases in areal density and speed are fairly predictable, as long as there are no trajectory-disrupting innovations.

Two types of trajectory-disrupting innovations can be distinguished: (1) a threat from competing technologies, and (2) break-through innovations in the drive design and in component technology that would drastically improve disk drive capacity, performance, and cost.

Let us first look at the threat from competing technologies. Hard disk drives constitute just one approach to the storage and retrieval of digital information. There are a number of competing technologies with different costs and benefits: optical storage offers higher capacity, tape drives lower cost, RAM chips far better speed, and flash EEPROMs more durability for portable applications.

While these technologies compete in niche markets, there is a widespread consensus that, so far, none of these competing technologies poses a serious threat to HDDs: "During the 1990s, it will be almost impossible for any competing storage technology to seriously challenge the rigid magnetic disk drive [i.e. HDDs], except in a few niche applications, as a result of the continuing rapid improvements in disk drive capacity, performance and cost. A few alternatives to magnetic disk recording have found a degree of acceptance in specialized markets and applications, but the proposed substitute must be significantly better, faster, smaller, less expensive or demonstrate some other overwhelming advantage."[48] However, a note of caution is in order: some engineers and managers who shape decisions in drive companies apparently believe that there may be a potential threat of displacement. Take the following observations by one of the engineering managers of Quantum's technology and engineering group: "When I left school in 1984 and was going to do disk-drive R&D at HP (Hewlett Packard), my friends said the 84-kbit chips were going to kill disk drives. The only reason the disk-drive industry is around is that [the disk drive] is less expensive than DRAM and flash. That always colors our thinking.... ".[49]

Industry, WSJ, April 22, 1996. Anyone familiar with the electronics industry, however, has learned that such brave predictions should never be taken at face value.

[48] "Technical Review," in 1995 DISK/TREND Report. Rigid Disk Drives, DISK/TREND, Inc., Mountain View, CA (October 1995), p. 27.

[49] As quoted in *The Electronics Engineering Times* (EET), January 16, 1995.

The second type of trajectory-disrupting innovations revolves around break-through innovations. Break-through innovations in architectural design and in component technology have periodically caused quite serious turmoil in the HDD industry.[50] Thus, HDD companies cannot afford to neglect such a possibility. Much depends on what kind of customers it is linked to. If these customers are established market leaders intent on sustaining the status quo, there is a danger that an HDD manufacturer may become locked into obsolete architectural designs. If, however, the HDD company succeeds in broadening its customer base to include computer companies intent on developing new markets and applications, there are much stronger incentives to proceed with architectural paradigm shifts. A passive subordination to customer needs can be a trap. Indeed, market leaders in the HDD industry often listened too attentively to their established customers and ignored new product architectures whose initial appeal was in seemingly marginal markets.[51]

Christensen argues that a firm's competitive position depends as much on the nature of demand as on the constraints resulting from available technologies. An exclusive focus on the development of key components may not be sufficient. Nor, for that matter, does a strength in architectural design alone guarantee competitive success. Both need to be combined with a capacity to identify and develop new markets for new applications. Strong product and market development capabilities are thus of critical importance.

Let me again emphasize an important feature of the HDD industry: drastic demand-related disruptions do not occur as frequently as in end-user industries such as PCs and consumer electronics. But they cannot be excluded. And when do they occur, they can have quite devastating effects on a company's competitive position. The conclusion that matters for our purposes is that no HDD company can afford to neglect the possibility of trajectory-disrupting innovations. This obviously adds quite substantially to the complexity of the competitive challenges in this industry.

Furthermore, due to the very short product life cycles that characterize the industry, demand-related volatility also occurs on a fairly regular basis. Product cycles for HDDs have been drastically cut. For high-end products, notably drives for servers and mainframe computers, they have fallen from 18-24 months to about 12 months. Product cycles are considerably shorter

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[50] For an excellent analysis, see Christensen [1993].
[51] Christensen [1993], p. 21-22.

for desktop applications and laptop PCs, where new drive generations are introduced about every nine and six months, respectively. Product life cycles in the HDD industry thus follow the same hectic rhythm that is now characteristic for the computer industry. For some segments of the industry, such as multimedia home computers, product cycles are now almost as short as those for fashion-intensive garments.[52]

Such short product cycles are an important source of volatility. Even with all the progress made in the flexibility of production, it is very difficult to avoid periodic mismatches between supply and demand. Each time the supply of HDDs overshoots demand, price wars are likely to occur. The result is that HDD producers must combine cost leadership with technology leadership, a combination which does not exist in the textbooks of competitive strategy.[53] Both have become inseparable. Some of our Quantum's highest volume products for personal computers rely on some very leading edge technology because our customers are demanding dramatic increases in the amount of storage in order to accommodate multimedia, larger software and access to databases. So they are pushing for very large, very cost-effective storage. To do that, we have to go to very high technology components and design approaches in order to get that kind of capacity in a cost-effective design. So... we're using leading-edge technology to produce very cost-effective, high-volume storage."[54]

3.4. Implications for Entry Barriers and Industry Structure

As competitive requirements have increased in complexity, the barriers to entry have risen across all stages of the value chain. We have seen that scale economies have rapidly increased for disk drive manufacturing. The same, however, is true for key components. Take, for instance, thin-film, the current dominant disk technology. The manufacture of thin-film sputtered disks is a complex, multi-step process that converts polished aluminum substrates into finished data storage media ready for use in a hard disk drive. The process requires the deposition of extremely thin, uniform layers of metallic film onto a disk substrate. To achieve this end, companies use a vacuum deposition, or "sputtering" method, similar to that used to coat

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[52] Based on author's interview at Acer, Taiwan, June 1995.
[53] Porter [1985], for instance, assumes that price competition and product differentiation can be neatly separated. For a similar assumption, see Kogut [1985].
[54] William Miller, former Chairman and CEO of Quantum Corp., as quoted in Electronics Business Asia, August 1995, p. 42.

semiconductor wafers. Vacuum deposition requires extremely expensive equipment and typically produces very low yields, thus leading to very high entry barriers.

Equally important are the entry barriers that result from the very complex R&D requirements that thin film media suppliers have to cope with. The effective implementation of thin film media technology requires simultaneous solutions to a variety of very complex problems, including magnetics, fly height, durability, and static friction. The same is true for alternative substrates, new magnetic alloys, and sputtering techniques.

Entry barriers are also high for head making, which is an extremely capital-intensive business. The production of inductive thin film heads, the dominant technology, is based on wafer fabrication techniques similar to semiconductor manufacturing and is characterized by very high investment thresholds. Entry barriers are even higher for leading-edge thin-film MR heads. Indeed, both scale and learning economies are orders of magnitude larger than for earlier generations of recording heads.[55]

In addition, due to drastically shortened product life cycles, time-to-market is essential for both media and heads: "...Early design-in wins are important because of steepening production ramps and shortening product life cycles. As manufacturers introduce new programs, companies must seek to qualify their heads in these new programs, which requires significant expenditures of time and resources."[56]

But entry barriers extend well beyond the sphere of production and R&D. We have seen that one of the peculiar features of this industry is the extremely complex nature of its supply chain. This has given rise to substantial entry barriers involved in the establishment of global supplier networks designed to guarantee timely access to key components. In addition, as product cycles have been cut short, this has led to a rapid depreciation of plants, equipment, and R&D, thus further increasing barriers to entry.

The result, not surprisingly, has been a tremendous increase in the degree of concentration in the industry. Since 1993, price wars and the resulting widespread losses that have swept the HDD industry have played an important catalytic role. One indicator of increasing concentration is the rapid decline in the number of worldwide drive manufacturers. The total number of producers has shrunk from 59 in 1990 to 24 in 1995, with most of the

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[55] For details, see Charles T. Clark, "Data storage making technological leaps," *Digital News & Review*, November 22, 1994.

[56] Profile of Suppliers of the HDD Industry: Media and Heads, by David McKendrick, June 21, 1996, p. 11.

decline taking place after 1993.[57] In 1995, nine companies went out of business while only three companies entered the fray. Importantly, all of the new entrants entered niche markets rather than volume production.[58]

Today, market share data shows that, by all standards, the HDD industry is characterized by a very high degree of concentration. American companies are clearly in a dominant position, with the top six HDD companies are all U.S.-based firms.[59] Japanese companies play only a minor role: their market share (as a percentage of worldwide sales revenues) peaked at 18 percent in 1990, and but has fallen since then as Japanese firms have been unable to cope with the rapid change in market requirements and technology. In 1994, Japanese firms had less than 15 percent of the market.

In 1994, the last year for which data are available, the four leading disk drive manufacturers control almost 73 percent of the world market (again for revenue shares).[60] For the non-captive market (i.e. exclusive of the large in-house sales of IBM, Fujitsu, Hitachi and other integrated computer companies), the share of the largest four companies was even higher and reached almost 85 percent.[61]

Concentration ratios are also quite high for the two main key components: heads and media.[62] In 1994, the largest 6 heads manufacturers accounted for 78 percent of all head-gimbal assemblies (HGA's) shipped, while the next 4 largest companies accounted for another 15 percent. U.S.-owned firms have 72 percent of the market and the Japanese 19 percent. Overall, the 10 largest companies have 93 percent of the market by volume.

[57] 1995 DISK/TREND Report. Rigid Disk Drives, DISK/TREND, Inc., Mountain View, CA (October 1995), p. 4.
[58] Two of the newcomers produce new high-end 3.5" cartridge drives (Iomega and Nomai), while Gigastorage International will revisit the 5.25" drive market with a new low-cost drive.
[59] A note of caution is in order here. Most statistics on the HDD industry are generated by the private consulting company Disk/Trend Inc. which defines the nationality of a manufacturer by the location of the firm's headquarters, regardless of the location of individual manufacturing plants. This creates no problem for Seagate which is obviously an American company, even though the firm manufactures most of its drives abroad. For Quantum, however, this definition becomes problematic, as Matsushita Kotobuki has moved from the humble position of a contract manufacturer of low-end drives to the sole source of Quantum disk drives, including its leading-edge products. The above definition becomes outright misleading in the case of Maxtor: while the headquarters of this company officially is located in Milpitas/CA, everyone knows that the Korean Hyundai group which has acquired 100% ownership, now calls the shots. One would thus be hard pressed to call Maxtor an American company today.
[60] The market shares of Seagate and Conner Peripherals have been lumped together, as Seagate acquired Conner in September 1995,DISK/TREND, Inc, 1995 DISK/TREND Report. Rigid Disk Drives, Mountain View, CA (October 1995).
[61] Disk/Trend Inc. figures, as quoted in Electronics Business Today, November, 1995, p. 41.
[62] Market shares are expressed by volume. From Profile of Suppliers of the HDD Industry: Media and Heads, by David McKendrick, June 21, 1996.

Compared with both HDD assembly and head manufacturing, the media industry is less concentrated. In 1995, the largest 6 media manufacturers accounted for 63 percent of all units shipped. The next largest 6 companies accounted for another 27 percent and another 6 or so companies fought for 7 percent of the market. A few of the smallest firms, however, are increasing production in 1996. Again, U.S. firms dominate, with 60 percent of the market, but Japanese firms have a fairly strong 33 percent market share.

The very high degree of concentration that characterizes the HDD industry raises the question whether the industry is controlled by a tight oligopoly. This is an important issue. If the industry is indeed governed by a tight oligopoly, this would imply that the development of technology, products and markets is shaped by a small group of American firms. It would also imply that outsiders from Japan or elsewhere would have very limited chances to expand their market share. The logical conclusion would then be to argue that, if such a stable oligopoly exists, U.S. firms would certainly have a choice to slow down their expansion of international production and may even consider bringing manufacturing back to the U.S.

According to Blair, one of the leading experts on oligopolistic competition, oligopoly begins when the four largest firms hold more than 25 percent of overall sales.[63] Between 25 and 50 percent, this oligopoly is loose and unstable, but above 50 percent, it becomes firm and clearly established. If we use this criterion, we would have to conclude that the HDD industry is indeed controlled by a very tight oligopoly. We can also use a second classification of market structure which is widely used in the literature and which goes back to the pioneering work of Bain.[64] He distinguishes three types of oligopolistic market structures: (1) "very highly concentrated oligopolies," where the top eight firms control 90 percent of the market and the top four 75 percent; (2) "highly concentrated oligopolies," where the respective shares are 85-90 percent and 60-65 percent; and (3) "high-moderate concentrated oligopolies," where corresponding control is 70-85 percent and 50-65 percent. Using this classification, we would again be forced to conclude that the HDD industry is definitely a "very highly concentrated oligopoly."

This conclusion, however, does not square well with the fact that the HDD industry is characterized by continuous price wars, very short product cycles, and highly volatile market

[63] Blair [1972].
[64] Bain [1959].

positions. Despite a number of major shake-outs (the last one in 1993), we find that the industry remains highly unstable. As a result, no firm, not even the current market leaders IBM and Seagate, is safe from a sudden reversal of its fortunes.

Market leadership positions change hand in this industry at very short notice. Let us look at the figures for the non-captive HDD market.[65] In 1992, Conner Peripherals was the market leader with 24 percent. In 1993, however, Quantum had leapfrogged both Conner and Seagate to become No. 1. From 15.3 percent in 1992, Quantum increased its market share to nearly 21 percent in 1993 and 23 percent in 1994. Conner Peripherals in turn fell back to the third position, and has seen its market share erode to 16 percent in 1994. Preliminary data for 1995 show that, once again, the industry has experienced another round of swapping market leadership positions, with Seagate now re-capturing the top position from Quantum.

We are thus faced with an interesting puzzle. Despite an extremely high degree of concentration, the HDD industry does not display any of the features of a stable global oligopoly: market positions are volatile, and late entrance is possible, at least in newly emerging niche markets. In short, we are dealing here with a highly unstable global oligopoly. The consequence is ruthless competition across the board. This implies that firms in this industry may have very little choice but to vigorously pursue their expansion into international production.

One final comment on how the HDD industry fits together with the rest of the electronics industry. Put simply, important differences exist in the competitive requirements that set the HDD industry apart from other sectors of the electronics industry. Nevertheless, we find a strikingly similar impact on market structure: a rapid pace of technical change, combined with extreme volatility has led to an erosion of established market leadership positions. Let us now inquire how this affects the organization of international production.

Chapter II: A Shift from Partial to Systemic Globalization: Key Features of International Production Networks

How has the increasing complexity of competitive requirements that I have described in chapter I affected the organization of international production in the electronics industry?

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[65] In the HDD industry, non-captive sales are defined as "... [a]ny public sale or lease by any disk drive manufacturer, except sales or leases of internally manufactured disk drives by computer system manufacturers primarily for use with their own systems." (1995 Disk/Trend Report, p. 50). For instance, shipments by IBM are non-captive, except for drives sold with systems made by the parent company or other subsidiaries.

In order to answer this question, I first describe a fundamental puzzle related to international production (II.1). We then consider some conflicting determinants of international production (II.2). In section II.3, I analyze why partial forms of globalization are inadequate to cope with these requirements. Finally, in section II.4, I introduce the concept of the international production network that I will use in chapters III and IV to describe key features of systemic globalization in the electronics industry.

1. A Puzzle

There are two fundamental reasons why a firm is normally reluctant to engage in international production: (1) it fears that geographic dispersion will weaken existing governance structures, with the result that control over strategic resources and capabilities will erode; and (2) it fears that distance will magnify the impact of unexpected disruptions in its value chain and will thus lead to substantial coordination costs.

One of the great advantages of concentrating production within a region is that material inputs, ideas, and finance can move more quickly back and forth across different stages of the value chain. A region guarantees proximity which facilitates close interaction between different nodes of the value chain. In short, by concentrating production within one region, a firm can generate closer, faster, and more cost-effective interaction between different stages of the value chain than it can ever hope to achieve once it starts moving production abroad.

Yet, despite the fundamental advantages of keeping production at home and at close proximity, electronics firms have almost invariably moved to international production once they reach a certain size. This raises an intriguing question: Why is it that, despite the advantages of proximity, electronics firms have moved to international production?

Logically, there are three possible solutions to this puzzle. First, proximity matters and works best at home. Yet, there may be other more important concerns that force companies to shift to international production and to disregard the advantages that result from co-location. Second, some forms of proximity may be less constraining than others to a redeployment of production overseas; in other words, it may actually be possible to reproduce these particular proximity effects at some of the foreign locations. Third, the link between close cooperation and co-location may be somewhat looser than is normally assumed in the literature. There may thus be alternative and more indirect ways to achieve close cooperation that do not necessarily require physical co-location.

I will discuss in chapter IV the last two of these three possibilities. We will see that, in some cases, there may well be alternative and more indirect ways to achieve close cooperation that do not necessarily require physical co-location. We will also see that, in certain cases, key support functions have migrated abroad, with the result that a firm can now co-locate abroad an increasing variety of value-chain functions. Our focus here will be on those conflicting determinants of international production that may induce a firm to disregard the advantages of home country co-location.

2. Conflicting Determinants of International Production

We are interested in the factors that have shaped the organization of international production. These factors are more complex than is assumed by conventional economic theory. The need to reduce costs to offset an erosion of the home country comparative advantages is an important catalyst, but no more. More fundamental forces are at work. A firm-level perspective can help to identify some of these forces.

There is a rich body of literature that describes what benefits a firm can reap from a shift to international production.[66] For quite some time, the focus has been on two aspects: the penetration of protected markets through tariff-hopping investments and the exploitation of international factor cost differentials, primarily for labor. This has given rise to a peculiar pattern of international production where offshore production sites in low-cost locations are linked through triangular trade with the major markets in North America and Europe. The hallmark of this pattern of international production was that it led to a clear-cut division of labor and that locational decisions were shaped by fairly straightforward criteria.

Over time, it became clear that while both market access and cost reduction were important, they were no longer the only important factors. Today, international production involves a much more complex agenda. Both market penetration and cost reduction have to be reconciled with a number of equally important requirements, including the exploitation of uncertainty through improved operational flexibility,[67] a compression of speed-to-market through

[66] Good overviews are Dicken [1992] and Dunning [1993].
[67] Kogut [1985b], and Kogut and Kulatilaka [1994].

reduced product development and product life cycles,[68] learning and the acquisition of specialized external capabilities,[69] and a shift of market penetration strategies from established to new and emerging markets.[70]

3. The Limits to Partial Globalization

It soon became obvious that, in order to reap such a broader set of benefits, firms needed to be able to coordinate global operations and resources within increasingly tight time schedules and that this required a shift away from partial to more systemic forms of globalization.

- Partial globalization is characterized by a loose patchwork of stand-alone affiliates, joint ventures, and suppliers that are scattered across the globe and that co-exist without much interaction. It is partial in the sense that the firm cannot reap the full benefits of international specialization. In essence, this is due to an absence of interactions across functions and locations and to inadequate coordination approaches.
- Systemic globalization, on the other hand, implies that a company attempts to network its operations and inter-firm relationships worldwide, both across functions and locations. It is systemic, as the firm can now generate closer, faster, and more cost-effective interactions between the different nodes of these international production networks. By providing more cost-effective ways of coordinating these interactions, systemic globalization enables the firm to internalize, on an international scale, resources and capabilities without running into the constraints of excessive centralization.

Historically, partial globalization came in a variety of forms. All these forms, however, shared a constant tension between centralized and decentralized governance structures. While some forms of partial globalization can have considerable advantages, they all fail to establish two-way flows of information that are essential for a firm's quick and flexible response to unexpected disruptions and changes in markets and technology.

I distinguish four forms of partial globalization: (a) the complete centralization of production in one location, usually the home country of the corporation, that serves as the sole export platform; (b) attempts to shift from export-led to investment-driven international market share expansion through the wholesale transfer of the domestic production system; (c) a progressive decentralization of international production, both in terms of geographic disperson and in terms of the governance structure; and (d) attempts to shift to so-called "global strategies"

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[68] Flaherty [1986], Stalk and Hout [1990], Womack, Jones and Roos [1990], Clark and Fujimoto [1991].
[69] Winter [1987], Chesnais [1988, 1995], Bartlett and Ghoshal [1989], Teece, Pisano and Shuen [1992], and Stopford [1994].
[70] Levitt [1983], Kotler et. al. [1985], and Ernst and O'Connor [1989].

where the parent company tries to impose centralized control over existing international operations and suppliers.

Global strategies are included under partial forms of globalization because they fail to fulfill an essential prerequisite of systemic globalization: the establishment of two-way flows of information across all network nodes.

(a) Complete centralization

International market share expansion through exports was rarely a viable long-term proposition. Once these exports became too successful in penetrating foreign markets, this invariably gave rise to import restrictions. Thus, only a few industries were able to sustain complete centralization. Probably the most prominent example is the aircraft industry, where some sort of complete centralization was made possible by a combination of very high investment thresholds, very high transportation costs for heavy and complex parts and components, and the possibility to negotiate access to government procurement markets.[71]

(b) Attempts to transfer the domestic production system

Perlmutter [1969] has shown that once a firm decided to shift from exports to international production, it almost invariably started out by "exporting the home organization overseas." American firms had a particularly strong preference for this wholesale transfer of the domestic production system. Given the size of the domestic market, "...it is not surprising that American firms should resist having the international tail of their operations wag the dog." (Kogut [1985b], p. 32). At the same time, a tradition of strong financial control systems has fostered an illusion by American managers that they could easily standardize their international control systems.[72]

(c) Decentralization of international production

Attempts to decentralize international production, our third form of partial globalization, has been around for quite some time. European firms, many of whom entered international production during a period of severe protectionism, preferred decentralized governance structures "in order to establish an identity as a collection of national companies." (Kogut [1985b], p. 32). Also, the much smaller domestic markets and underdeveloped financial control systems added to this focus on decentralization.

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[71] Since the 1970's, the increasing reliance on off-set local procurement arrangements and the spread of joint ventures and strategic alliances has eroded the degree of centralization. For details, see Mowery [1991].

[72] McInnes [1971]. See also Johnson and Kaplan [1994] for a fascinating account of how a once widely acclaimed organizational innovation, the American system of management accounting, has become obsolete in the face of the requirements of globalization.

Until around the mid-1980's, decentralized forms of international production were very much in vogue among the leading firms in the electronics industry. Representative examples included numerous powerful market leaders, including Philips, Siemens, GE, and IBM. Their early entry into international production was based on the concept of multi-nationality: overseas affiliates would focus primarily on country idiosyncracies. Decentralization of control down to the level of regional headquarters or even some of the larger overseas affiliates was perceived to be a prerequisite for achieving this goal. Over time, this led to the emergence of powerful regional fiefdoms that were used to acting on their own: "After years of relative independence, many subsidiaries have developed cultures, systems and structures that are incompatible with those of the parent."[73] Such partial forms of globalization had their historical advantages; in particular, they were good at exploiting peculiar features of national markets and production systems. The fact that these advantages came at a heavy cost and that numerous overseas affiliates were almost impossible to coordinate did not matter very much as long as many of these national markets were highly protected. Decentralization thus originally reflected the logic of rent-seeking investment.

In principle, as Salter (1960) has shown, plants of very different vintages can co-exist competitively as long as they are producing different qualities for different market segments at different prices. Low productivity production for a particular market can in fact be highly profitable, if the market is highly protected. This logic, however, ceased to work once competition began to cut across national borders and became "global." From that moment on, multinational corporations began to look for approaches to the organization of international production that would allow them to improve the allocation of their different value chain functions across national borders and to integrate them into their global strategies.

(d) Attempts to shift to so-called "global strategies"

Our fourth category of partial globalization is attempts to move toward systemic globalization, albeit largely unsuccessful attempts. Especially for American companies, the first response was to shift to fairly extreme forms of centralization where the parent company tries to recapture control over existing international operations and suppliers.[74] These attempts included the creation of world product lines (Ford's "world car" concept being the most prominent

[73] Morrison and Roth [1992], p. 42.
[74] This transformation is documented in Stopford and Wells [1972]. For similar attempts by European companies, see Franko [1977].

example), divisions along regions (with the U.S. being the epicenter and Europe playing the role of a "junior partner"), and matrix structures. In the end, these attempts failed as they were based on unrealistic assumptions concerning the capacity to exercise centralized control over worldwide markets and production sites.

Starting in the late 1970's, many American electronics companies became obsessed with the idea that Japanese firms owed much of their success to their capacity to orchestrate, in a highly centralized manner, worldwide market share expansion strategies. Global strategies, in this view, can be defined as "... the cross-subsidization of market-share battles in pursuit of world-wide production, branding and distribution advantages." (Morrison and Roth [1992], p. 40). It was felt that such a strategy could only be implemented if the parent company was able to exercise tight control and coordination over international production activities: "High-value activities are typically located in the home country; the activities of overseas subsidiaries are rationalized with little input in decision-making coming from abroad. That tight central control relegated overseas subsidiaries to primarily downstream, low-value-adding activities where strategy implementation became a critical responsibility." (Morrison and Roth [1992], p. 40-41).

With the benefit of hindsight we know today that this view is only partially true. In their rush to catch up in international production, Japanese strategists may have originally hoped to be able to implement such a globally standardized approach to international production. Yet, reality was very different. Over time, the transfer of the Japanese production system to overseas locations has been faced with increasing constraints. This has forced Japanese firms to adapt key features of their production networks and to introduce at least some elements of decentralization.[75]

However, this did not prevent many American and European firms, at least in their initial response, from adopting centralization strategies. Reducing transaction costs and risks through global sourcing and marketing strategies was one important motivation. Another expectation was that centralized control would help to keep a tighter rein on technology leakage that could benefit their Japanese rivals. While some of these effects did materialize, a high degree of centralization soon turned out to be of doubtful value. Top-down approaches to centralization, combined with pervasive "down-sizing" exercises, created substantial turmoil and resistance. When the parents

[75] This story is told in some detail in Abo [1993] for Japanese investments in the U.S. and Europe, and in Ernst [1994c, 1997b, 1997c] for such investments in East Asia.

attempted to rein in unwieldy satraps and to re-establish centralized control, they were often bitterly opposed by foreign subsidiaries eager to protect their independence.

But much more important were some other negative effects of centralization. In many cases, it obstructed a firm's ability to learn and to build capabilities quicker and at less cost than its competitors. Centralized governance structures share one common feature with the ill-fated attempts of central planning: the headquarters is cut off from reliable feedback from local actors. The result is that the parent company frequently knows very little about the real opportunities and challenges in specific markets and locations. This clearly indicates a need to "...move away from a rigid, hierarchical and centralized command structure towards a more decentralized and open management system" that would not repeat the short-comings of the earlier forms of partial globalization.[76]

4. Systemic Globalization: The Concept of the International Production Network

It is with regard to this challenge that firms are now searching to establish more systemic forms of globalization. In essence, this implies that a company attempts to organize its worldwide operations and inter-firm relationships as part of international production networks. The over-riding concern is to generate, across national borders, closer, faster, and more cost-effective interactions between different stages of the value chain.

4.1. Levels of Analysis

The firm as a networked organization is the unit of analysis.[77] Our network definition originates from debates among industrial economists and management theorists who define the multinational corporation as "a network of activities located in different countries."[78] Due to the limitations of partial forms of globalization, multinational corporations do not have much choice but to proceed with the development of international production networks. Indeed, they cannot go backward to complete centralization of manufacturing or they will lose access to essential markets. Nor can they remain a disconnected system of geographically scattered operations. International production networks result from an attempt to combine the scale economies of

[76] Howells and Wood [1991], p.166.
[77] Johanson and Mattsson [1988], p. 312. See also Hakansson [1990] and OECD [1992], chp. 4.
[78] Kogut and Kulatilaka [1994], p.123. For good overviews of these debates, see Dicken [1992], chp. 7, and UNCTAD [1994], chp. 3.

centralization with the flexibility of decentralization and the vast opportunities for learning and time compression that are typical for networks.

The concept of an "international production network" is an attempt to capture the spread of broader and more systemic forms of international production that cut across different stages of the value chain and that may or may not involve equity ownership.[79] This concept allows us to analyze the globalization strategies of a particular firm with regard to the following four questions: (1) Where does a firm locate which stages of the value chain? (2) To what degree does a firm rely on outsourcing and what is the importance of inter-firm production networks relative to the firm's internal production network? (3) To what degree is the control over these transactions exercised in a centralized or in a decentralized manner? and (4) How do these different elements of the international production network hang together?

As a first approximation, an international production network combines a lead firm, its subsidiaries, affiliates and joint ventures, its suppliers and subcontractors, its distribution channels and VARs, as well as its R&D alliances and a variety of cooperative agreements (such as standards consortia). The lead company derives its strength from the intellectual property and know-how associated with setting, maintaining and continuously upgrading a de facto market standard. This requires perpetual improvements in product features, functionality, performance, cost, and quality. The lead firm outsources not only manufacturing, but also a variety of high-end support services. The result is that an increasing share of the value-added shifts across the boundaries of the firm as well as across national borders. Competitive success thus critically depends on a capacity to orchestrate and coordinate such complex international production networks and to integrate them into the firms organization.

4.2. Basic Definitions

In a moment, I will describe some of the indicators that can help us to address these four questions (see section II.4.5.). First, however, let us look at some basic definitions. Networks differ from both markets and hierarchies (as defined by Williamson [1975 and [1985]) and constitute a sui generis form of organizing economic transactions.[80] International production networks constitute an important departure from traditional forms of organizing international

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[79] For details, see Ernst [1992, 1994b, 1994c, 1997c].
[80] Powell [1990], and Forsgren and Johanson [1992], p. 7.

trade, production and technology flows. In short, arms-length market transactions and equity forms of investment no longer are the only forces which shape the organization of cross-border economic transactions.

I talk about production networks, and define production broadly to include the production of goods as well as services. Such a broad definition is used in order to avoid some of the shortcomings that result from a narrow analytical focus that is exclusively concerned with manufacturing. Companies increasingly seek value-added (i.e. profits) in the non-manufacturing side of production, or what others call "intangible investments" or "production-related support services."[81] This is true in particular for design and engineering, supply logistics, and sales and marketing (especially distribution). The choice of a broad definition of production reflects our specific interest: we want to understand to what degree the redeployment of manufacturing to overseas locations will lead to a concomitant redeployment of production-related support services.

The term international production is used when a firm " controls production assets in more than one country,"[82] with the result that national production systems interact. This definition immediately raises the question of how we define control. For some observers, like John H. Dunning, control requires some sort of equity ownership. For Dunning, "international production" requires a "framework of common ownership" where the parent company acquires an equity share in the overseas operation.[83] International production thus requires FDI, while non-equity forms of overseas operations are called "international sourcing."

There is now a large body of literature which clearly indicates that non-equity forms of international production have considerably increased in importance over the last decades.[84] Examples include the spread of licensing agreements, management contracts, subcontracting and contract manufacturing arrangements, consignment manufacturing, and product franchising. It thus appears to make little sense to base a definition of "international production" simply on the criterion of equity ownership. Levy and Dunning (1993, p.18) admit this, at least implicitly, when they characterize both subcontracting and strategic alliances as "...hybrid structures of ownership and control that blur the distinction between ... [international production and

[81] OECD [1992], chp. 4 documents the growing importance of intangible investments for value generation.
[82] UNCTAD [1994], p. 118.
[83] Levy and Dunning [1993], p. 15.
[84] For a good overview, see Contractor [1994].

sourcing]." In line with the United Nations World Investment Report (1994, p.18), we use a broader definition of international production where control over foreign production assets" is typically established through FDI, but can also be exercised through various non-equity forms."

This in fact is the Achilles' heel of research on globalization. Most research has focused on the spread of equity FDI but has neglected the role of a variety of non-equity links, especially with smaller firms which would not have been able to participate in international production on their own. Indeed, small and medium-size enterprises (SMEs) have become important carriers of systemic globalization and help to fill in the interstices of international production that large MNCs are unable to detect and deal with. As suppliers, subcontractors, and matchmakers for market penetration, SMEs act as a convenient buffer against uncertainty and provide cheap, flexible and quick sources of supply for a variety of production inputs. Our definition of international production is thus deliberately broad in order to be able to address this important blank spot of globalization research.

4.3. Intra-Firm Versus Inter-Firm Production Networks

Production networks can exist within a firm (intra-firm networks) or they can link the firm to other, formally independent companies (inter-firm networks). Intra-firm networks link together, within a firm, different divisions and business functions, such as R&D, design, engineering, procurement, production, marketing, sales, and customer services. They enable the firm to overcome the "Taylorist" separation of different business functions and to pursue them simultaneously. Empirical research has identified three main impacts of such networks: (1) links between marketing, design, and manufacturing become closer; (2) throughput time and speed-to-market are shortened; and (3) feedback information on customer requirements and supplier capabilities are channeled more rapidly to product design and production planning.[85]

Inter-firm production networks are an important feature of the shift to systemic globalization; indeed, firms are increasingly developing a variety of increasingly dense linkages with formally independent firms. Frequently, these linkages cut across national boundaries. Such cross-border inter-firm production networks cover the whole gamut of industrial manufacturing, from component production to final assembly. Increasingly, they also include such knowledge-

[85] For a good overview, see OECD [1992], chp. 4. See also Baldwin and Clark [1996].

intensive activities as marketing, standardization, product design, the development of production technology, generic technologies, and scientific knowledge.

I distinguish five types of inter-firm production networks:[86]

(1) Supplier networks between a client (the "focal company" which can be either a manufacturer/final assembler or mass merchandiser) and its suppliers of intermediate production inputs, such as materials, parts and components, sub-assemblies, and software. Supplier networks are defined to include subcontracting and a variety of other arrangements, such as consignment assembly, original equipment manufacturing (OEM), original design manufacturing (ODM), "contract manufacturing," and "turnkey production."

(2) Producer networks are defined to include all co-production arrangements that enable competing producers to pool their production capacities, financial capabilities, and human resources in order to broaden their product portfolios and geographic coverage.

(3) Customer networks are defined as the forward linkages of manufacturing companies with distributors, marketing channels, value-added resellers, and end users, in order to facilitate the penetration of existing markets or the development of new markets.

(4) Standards coalitions are initiated by potential global standard setters with the explicit purpose of locking-in as many firms as possible into their proprietary product, architectural, or interface standards.

(5) Technology cooperation networks facilitate the exchange and joint development of product design and production technology, involve cross-licensing and patent-swapping, and permit the sharing of R&D. Under such arrangements, knowledge typically flows in both directions and all participants need to master a fairly broad array of technological capabilities.

Intra- and inter-firm networks hang together and cannot be separated from each other. A firm that tries to improve the integration of its internal value chain, for instance through "just-in-time," "concurrent engineering," or "design for manufacturing" techniques, can only do so if it succeeds in integrating a multitude of relationships with outside firms.[87] Today, firms invariably depend on external sourcing for a variety of intermediate inputs, including materials, parts, components, and sub-assemblies, as well as software and knowledge-intensive support services. At the same time, firms are critically dependent on close links with customers, as "...it is no longer sensible to assume seller-dominated markets where the firm, as the focal unit, sets the parameters and the faceless market responds."[88]

[86] For a detailed analysis of inter-firm production networks, see Ernst [1994b].
[87] Firms differ in their precise definition of "design-for-manufacturing" (DFM) guidelines. These definitions also differ across products and time. Apple Computer, for instance, developed DFM guidelines in 1990 for PCBs that were intended to ensure that boards could be fabricated by at least two of its PCB suppliers and could then be assembled at any of its plants. See Levy [1994], p. 343.
[88] Easton [1992], p. 7. For evidence on the shift from sellers to buyers markets in some sectors of the electronics industry, see Ernst and O'Connor [1992], chps. 1 and 2.

In short, the expected advantages of intra-firm networks will only materialize if they are extended to integrate at least some of the more important outside suppliers and customers. The difference between the internal organization of a firm and its outside relations becomes blurred, however, as external sourcing for parts and components as much as for product designs and production technology gains in importance and as organized markets within firms expand. As we will see in chapter IV, the cost of coordinating such outside relations now exceed the cost of internal value generation for many firms. Coordinating inter-firm production networks has thus become a crucial concern for strategic management.

4.4. Governance Structures

This then raises one last set of issues: the search for adequate governance structures. Governance describes how, within any particular network, control and coordination is exercised and by whom. It consists of common methods and procedures that shape the behavior of network nodes, including budgetary rules and procedures, evaluation procedures, personnel management practices, database management, and quality control norms. Network nodes can be equity-owned affiliates and those legally independent firms that participate in the core company's inter-firm networks.

Governance structures can be centralized or decentralized, and they can be strong or weak. A centralized governance structure, in turn, implies that the core company (the network center) exercises full control over all network activities. A decentralized governance structure implies that individual network nodes have a certain degree of decision autonomy. Strong governance implies that control and coordination are enforced over a broad range of value chain activities and are shared by a large number of network nodes. Weak governance, in turn, implies that control and coordination can be enforced only over a limited range of activities and that only a limited number of network nodes are subordinated to the core company.

Our earlier discussion (in section 3 of this chapter) of the limits of partial globalization demonstrated that neither extreme forms of decentralization nor extreme forms of centralization are able to provide sufficiently strong governance to cope with the increasingly complex competitive requirements. In essence, the spread of international production networks is an attempt to steer clear from both extremes and to develop more cooperative, two-way forms of cooperation between the parent company, its affiliates, and network partners.

Attempts to move to network governance structures gives rise to two fundamental dilemmas. First, by moving away from a centralized, hierarchical governance structure to improve responsiveness and flexibility, the company may lose its ability to coordinate its global operations, leading to a duplication of efforts, lack of compatibility, an increased potential for intense rivalry among individual network nodes, and to a sub-optimal allocation of resources. Decentralization of control thus needs to be complemented with some centralization of coordination functions.

A second dilemma relates to the control over key resources and capabilities. If the core company continues to rely on centralized control, it may forgo important learning and capability formation possibilities, and hence end up with a non-competitive production system. If, on the other hand, the core company proceeds too quickly with decentralization, this may lead to a substantial leakage of core capabilities to individual network nodes. Sooner or later this may lead to the disintegration of the network and the emergence of strong new competitors.

The search for adequate governance structures is thus bound to be a slow process based on trial-and-error. The result is that different firms may pursue quite distinctive approaches. They may also try to blend elements of different governance structures, with the result that hybrid forms of organization are likely to emerge.

4.5. Indicators

Empirical research on the structural features of international production networks is still at an exploratory stage and we thus lack a widely accepted set of indicators. I have chosen a broad set of indicators in order to demonstrate the tremendous complexity involved. Later research will have to narrow down and simplify these measures in order to be able to quantify them. The Sloan Foundation study on the hard disk drive industry provides an opportunity to do this for a limited set of indicators that are of relevance for the HDD industry.

I distinguish two fundamental aspects of systemic globalization: geographic dispersion and increasing complexity. Under the first heading, I distinguish a quantitative dimension, where a company extends its global reach, and a qualitative dimension, which describes the development of spatial concentration and the resultant specialization patterns. Indicators on the quantitative aspects of geographic dispersion include: (1) information on the location of affiliates, suppliers, and distributors; and (2) information on the location of other value-chain activities, such as engineering and R&D.

Indicators on the qualitative aspect of dispersion include: (1) changes in the mix of products that are produced overseas, where we find that the product life cycle (PLC) theory ceases to hold; (2) a broader scope of value chain activities that move abroad, with a special emphasis on the migration of key support functions; (3) the increasing importance of global sourcing and its continuous tension with integration; and (4) systemic rationalization which, by incorporating proximity advantages abroad, leads to the joint migration of key support functions.

Chapter III deals with geographic dispersion, while chapter IV addresses the complexity issue. I will use the above set of indicators to trace the shift from partial to systemic forms of globalization in the electronics industry. Again, I will proceed from the general to the specific. I will first try to paint a broad picture of developments in the electronics industry. Wherever possible, I will try to specify some of the peculiar features of the HDD industry. Where this is not possible, I will use examples from other sectors of the electronics industry and identify possible implications for research on the HDD industry.

Chapter III: Geographic Dispersion

1. The Concept of Geographic Dispersion

The most basic feature of an international production network is that its different nodes become increasingly dispersed. This implies, first and foremost, a rapid geographic dispersion, with the result that a particular firm now has to coordinate its value chain across different time zones and continents. Dispersion also implies that individual network nodes become more distinct from one another, as they are exposed to a wider sets of environments. We will see that there is a strong link between spatial expansion and growing diversity and that, as a result, firms differ in how they approach the organization of international production.

A second important issue is that geographic dispersion is not only a quantitative phenomenon (i.e. where a company extends its global reach) but also has a qualitative dimension which involves the development of spatial concentration and the resultant specialization benefits of such dispersion. I call the first effect "geographic widening" and I use the term "geographic deepening" to describe the second effect. Both widening and deepening hang together, with the result that an analysis that only focuses on widening effects would loose sight of important elements of the overall picture.

This brings us to a third important issue. As geographic dispersion proceeds, new opportunities for specialization open up. Specialization implies that, by devoting itself to a particular set of goals and capabilities, a firm can reap substantial advantages. Thus, in establishing an international production network, a firm has to struggle with a number of intricate trade-offs: should the focus of specialization be on individual country idiosyncracies, on establishing a regional division of labor (i.e. within a macro-region such as East Asia), or on the firm's global strategy?

For each node of an international production network, three sets of indicators can be used to determine specialization; (1) the destination of sales and their product composition; (2) the origin of purchases and their product composition; and (3) the degree of interdependence between different network nodes. Following McKendrick et. al. [1994, p.18], I use four indicators to describe the progression from partial to systemic forms of specialization along a continuum that ranges from total independence to close interdependence; <u>(i) independence</u>: network nodes neither share the same processes, nor do they have common input requirements nor output destinations; <u>(ii) pooled interdependence</u>: nodes use similar processes and technologies and have similar output destinations, but they operate largely independently from each other; <u>(iii) sequential interdependence</u>: the output of one sub-unit becomes the input of another sub-unit; and <u>(iv) reciprocal interdependence</u>: the output of the corporation requires continual interaction between its sub-units/network nodes.

A fourth aspect needs to be added. In order to capture the speed and scope of geographic dispersion, it is no longer sufficient to consider only information on equity-based FDI. Of equal importance are links with formally independent firms, which may be suppliers, customers or, in some cases even competitors.[89] Only collecting information on the location of equity-owned affiliates would give us a distorted picture of the extent of geographic widening and deepening.

In what follows, I trace the process of geographic dispersion of the electronics industry into East Asia.[90] We will see how geographic widening and deepening have interacted in this

[89] We will address one important aspect, the spread of international supplier networks, in more detail in chp. IV below.
[90] There are two reasons for this focus on East Asia: (1) most of the literature on globalization has focused on geographic dispersion within the Triad, i.e. between the U.S., Japan and Western Europe; and (2) East Asia has

region, and how both have given rise to emerging specialization patterns. We will also see that, over time, geographic dispersion has occurred in an increasing variety of forms and that non-equity forms of international production have increased in importance.

In section 2, I show how American electronics firms have acted as pace-setters of geographic dispersion, especially into East Asia. In section 3, I describe how Seagate, one of the pioneers of aggressive geographic dispersion, has developed its Asian production network. This is contrasted in section 4 with two very different approaches: a heavy reliance on outsourcing, as represented by Apple, and a reluctant shift to Asia, as represented by IBMs Storage System Division (IBM-SSD). We will see how peculiar features of product mix and strategy have shaped these different approaches to geographic dispersion. Finally, in section 5.1., describe the ascent of Japanese production networks in Asia and document some important changes in their locational and specialization patterns.

2. American Firms as Pace-Setters

Looking back at the development of the electronics industry after World War II, we find that one of its hallmarks has been the fast pace of geographic dispersion. The war destroyed almost all the international production in existence during the previous decades. Afterwards, the establishment of the European Common Market was the catalyst which led, during the 1950's, to a first round of American investments in Europe, primarily in consumer electronics and office equipment, and then gradually in some related components. During that period, geographic dispersion was driven primarily by a concern to be present in the potentially huge future European market.

One of the early pioneers of geographic dispersion was IBM. Its move toward an integrated, worldwide operation dates back to 1949, when its World Trade Corporation was established.[91] IBMs "interchange plan" in Europe during the 1950's is probably one of the first systematic attempts to optimize its international operations by establishing a transatlantic production network.[92] These efforts became much more systematic with the introduction of the IBM 360 during the early 1960's. Essential for its success was a concerted effort of IBM R&D

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rapidly emerged as a major location for the electronics industry, and this is especially true for the disk drive industry.

[91] Brock [1975].

[92] Based on comments, received from David McKendrick, dated August 15, 1996.

laboratories and production facilities in the U.S. and Europe. The higher-end version 360/40, oriented toward scientific applications, was based on a design developed in IBMs Hursley laboratory in Britain while the low-end 360/20 was developed in IBMs German labs in Boeblingen.[93] The development of IBMs 360 mainframe system thus marked an important milestone in the move beyond partial globalization. By the mid-1960's, IBM had established a transatlantic production network where product development and manufacturing responsibilities were assigned to individual laboratories and production facilities. Each development laboratory specialized in a particular technology and carried the development responsibility for a product or technology for the entire company. Each IBM plant, including U.S. facilities, was given a mandate to produce specific products both for the international and the local market.

IBM was thus the first computer company to try a full-scale extension of its value chain across national boundaries, albeit still confined to the U.S. and Europe. This began to change during the 1960's. To reduce costs in manufacturing core memories for the 360 System, IBM began to shift the labor-intensive assembly of these components to low-cost "offshore" locations in Asia.[94] IBMs production network thus began to move beyond the transatlantic region: "An organization was quickly established in Japan to find vendors to [wire core arrays by hand]. Soon the work expanded to Taiwan, where a few thousand people were employed wiring core frames by hand. It was slow, tedious, meticulous work, stringing wires in just the right manner through each of the thousands of tiny cores in each core plane. But the cost of labor there was so low that it was actually a few dollars [per unit] cheaper than with full automation in Kingston [New York]." (Pugh [1984], p. 250-251.)

IBMs move to Asia did not occur in isolation: it was soon followed by its competitors who also established core plane wiring operations in Taiwan and Hong Kong.[95] IBM thus gave rise to a new model of international production for American electronics firms: the redeployment of labor-intensive stages of final assembly to Asia. For quite some time, most of these activities were fairly mundane. Much of what was then called "offshore sourcing" investment consisted of screw-driver assembly, with very limited local value added and almost no local linkages.[96] This was originally an exclusive American affair. Two actors were the main carriers: (1) producers

[93] Based on Pugh [1984], OECD [1969], and Harman [1971].
[94] Pugh [1984], p. 250-51.
[95] Harman [1971].
[96] For an early analysis of offshore chip assembly in East Asia, see Moxon [1974], Lim [1978], and Ernst [1983].

and mass merchandisers of consumer devices, with GE and Sears & Roebuck being the most prominent examples; and (2) medium-sized semiconductor "merchant" firms that were then struggling to establish themselves as independent vendors on the open market.

It is important to note that the strategic rationale for redeploying production to East Asia was very different from the one that prevailed in Europe. Market access in East Asia was of practically no concern. The real goal was very simple: sourcing for the lowest-cost export platform location. This goal was shared by both the consumer electronics and the semiconductor firms. Yet, both differed in how they tried to achieve this goal. The producers and mass merchandisers of consumer devices had no intention to invest in their own production affiliates. Instead, they chose to focus on licensing, franchising, and other contract manufacturing arrangements that eventually gave rise to the now famous OEM (original equipment manufacturing) contracts.

In short, right from the beginning, the focus of expanding international production was on establishing inter-firm production networks controlled by the brand name company or the mass merchandiser.[97] As we will see in a moment, this type of indirect international production has recently gained in importance. The irony is that what is now praised by some as a hallmark of a new era of globalization, i.e. forms of international production that do not require equity control, has in fact been created in the low-tech part of the electronics industry and often out of sheer desperation. After all, farming out product designs, first to Japanese and later on to Korean and other Asian OEM suppliers, was only the last step in the demise of the American consumer electronics industry.

American semiconductor firms proceeded in a different manner by establishing their own affiliates which focused on very simple "screw driver" assembly. The pioneer was Motorola, which as early as 1967 established production lines in Hong Kong and South Korea. In 1968, National Semiconductor and Texas Instruments both chose to move into Singapore. Four years later, both companies established their IC assembly lines in Malaysia, and were joined in the same year by Intel.

Originally, the expansion of American semiconductor firms into East Asia was primarily driven by two concerns: access to cheap assembly hands and the large tariff reductions they

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[97] This type of arrangement comes close to similar arrangements that had been developed much earlier in the textiles industry. Gary Gereffi, an industrial sociologist who has studied the globalization patterns of the textile industry, calls such arrangements " buyer-driven global commodity chains." See Gereffi [1994], p. 16.

could reap by re-importing sub-assemblies from abroad.[98] The overriding goal was to improve return-on-investments [ROIs] through cost reductions that did not require the heavy capital outlays that would have been necessary for factory automation at home.[99] In contrast to the consumer companies, however, the semiconductor firms insisted on equity control through the establishment of 100-percent-owned affiliates in order to minimize the risk of technology leakage. This is in accordance with theories of FDI which argue that firms with strong proprietary advantages in technology have a preference for equity control. For American semiconductor firms, the early expansion of international production thus relied primarily on FDI of a fairly footloose nature.

Over time, this simple concern with short-term financial savings gave way to more complex motivations. During the late 1970's, it became clear that Japanese electronics firms had succeeded in establishing a credible challenge by automating their domestic production facilities. In response, American semiconductor firms were forced to develop an international production strategy that would allow them to preempt possible attacks by Japanese firms through rapid cost reduction.[100] It is during this period that companies like Intel, Motorola, and National Semiconductor began to upgrade and automate their existing offshore chip assembly plants. In order to do so, they had to develop, albeit grudgingly, linkages with local suppliers and support industries.[101]

The motivation changed again when the U.S. dollar appreciated during the early 1980's. In response, cash-stripped American semiconductor firms began to experiment with those forms of international production that did not necessarily involve equity control and which had been developed earlier on by their brethren in the consumer industry. Since then, there has been a proliferation of a variety of international contract manufacturing arrangements, ranging from contract assembly to complete "second sourcing" agreements. Geographic dispersion now increasingly relies on non-equity forms of international production, i.e. the spread of inter-firm production networks. Together with the continuous upgrading of existing affiliates, this has conveyed substantial competitive advantages to American semiconductor firms.

[98] For a detailed analysis of the then prevailing U.S. tariff scheme and its impact on offshore sourcing strategies of American companies, see Grunwald and Flamm [1985].
[99] Note, however, that IBMs aforementioned move to Japan and Hong Kong was driven by a more long-term strategic concern, i.e. an attempt to extend IBMs transatlantic production network into Asia.
[100] For a detaled analysis of the offshore chip assembly strategies of American companies, based on company interviews, see Ernst 1983 and 1987.
[101] For a systematic analysis of some impacts of such investments on Malaysia, see Rasiah [1994].

The early 1980's also witnessed an additional round of geographic dispersion by American electronics firms which originally focused on 100 percent-owned affiliates. This time, the lead players were computer companies and firms that produce related peripheral equipment and sub-assemblies. An American company, founded by an Indian with a Singaporean passport, played a pioneering role in establishing Singapore as an offshore production site for HDDs since the late 1970's. This company, named Tandon, has been one of the leading suppliers of HDDs, before it went out of business. It is also worth mentioning that Hewlett Packard (HP) had an affiliate in Singapore as early as 1970, although it was only in the mid-1980's that this affiliate shifted its focus from instruments and medical equipment to computer-related products. The real turning-point was in 1981, when two major companies, DEC and Apple, first moved to Singapore.

Since then, more first-league players of the American computer industry have moved production to East Asia. In 1982, DEC established a second affiliate in Taiwan. In the same year, Seagate, only three years after its founding, decided to move a large part of its HDD assembly to Singapore. One year later, in 1983, Seagate established a second affiliate in Thailand in the Bangkok metropolitan area. In 1984, DEC established an affiliate in Hong Kong, while Maxtor set its foot on Singaporean soil.[102]

Over time, some of these firms have substantially increased the number of production affiliates established in Asia. Ten years later, around 1995, Conner Peripherals had three affiliates (in Singapore, Malaysia and China), DEC had four (in Singapore, Taiwan, Hong Kong and China), HP had four (in Singapore, Malaysia, Taiwan and China), Maxtor had three (in Singapore, Hong Kong and South Korea), and Seagate had five (one each in Singapore, Malaysia and Indonesia, and two in Thailand).

3. A Sophisticated Asian Production Network: The Case of Seagate

Let us take a closer look at the pace and scope of Seagate's geographic dispersion in Asia. Among hard disk drive companies, Seagate has probably been the most aggressive in its focus on

[102] Some American computer companies have hesitated for quite some time before proceeding to establish their own affiliates in Asia. Take for instance Compaq, the current market leader for desktop PCs: it began to move to Asia only in 1987, with its first affiliate established in Singapore, which was followed by a second affiliate in China in 1993. The same is true for Quantum, which only in 1994 began to move to Malaysia and then to Indonesia one year later.

East Asia. It also has been a pioneer in establishing the Singaporean HDD industry as a springboard for the development of its increasingly important Asian production network.

Today, Seagate operates 22 plants worldwide: five in the US, five in Thailand, four in Malaysia, three in Singapore, two in Ireland, and one each in Indonesia, China and Scotland. Fourteen of these plants, i.e. 64 percent of the total, are located in Asia. Another widely quoted figure is that "...80 percent of Seagate's production..." takes place in five Asian countries: Singapore, Thailand, Malaysia, Indonesia and China.[103] The problem with these types of figures is that we are left in the dark about what is exactly measured. Indeed, there is reason to not take such figures at face value. Most of these figures are quoted in Asian sources, and thus may be politically motivated in order to show how much the company contributes to local content and development. Obviously, we need to probe deeper and check the validity of these claims.[104]

We will first focus on Seagate's equity-owned affiliates. We use two measures, capacity, as expressed in sq-ft, and the number of employees.[105] Both indicators document the astounding speed of expansion of Seagate's Asian intra-firm production network. Asia's share in Seagate's worldwide production capacity has increased from roughly 35 percent in 1990 to slightly more than 61 percent in 1995, an incredible speed of expansion. Seagate's capacity expansion into Asia has led to an equally dramatic decline in the share of the U.S. in Seagate's worldwide capacity--from roughly 58 percent in 1990 to 34 percent in 1995. During the same period, Europe's share declined from roughly 7 percent to slightly more than 5 percent.

Let us now look at the regional breakdown of Seagate's employment. Asia's share increased from around 70 percent in 1990 to more than 85 percent in 1995. Again, Asia's expansion occurs at the expense of the U.S. From 26 percent in 1990, the share of the U.S. in Seagate's world employment fell to 11 percent in 1995. Europe's share remains constant at a measly 4 percent level. The absolute figures speak for themselves: out of a total worldwide workforce of 65,000 in June 1995, Seagate employed 55,000 people in Asia.

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[103] *South China Morning Post*, May 16, 1995, and *Asiaweek*, March 17, 1995.

[104] Recent changes in the approach of the Internal Revenue Service (IRS) to overseas investment of U.S. HDD companies may have the consequence that HDD companies may be even more reluctant to discuss these issues. Last August, the IRS demanded that Conner pay an extra $43 million and Seagate pay an extra $78 million in taxes for taxes and costs they saved at their Asian production facilities in the late 1980s and early 1990's. The IRS is now auditing their books for 1991 through 1993. The IRS argues that both companies have failed to keep "arm's-length" distance from their overseas affiliates, as required under U.S. tax law. It is in response to this threat that Seagate and Conner have drummed up their PR machines to talk about the growing decision autonomy and independence of their overseas affiliates.

[105] Seagate Profile, compiled by Allen Hicken, November 6, 1995.

The fact that Asia's share in employment is substantially higher than its share in capacity, while the opposite is true for the U.S., indicates a clear-cut division of labor: labor-intensive volume manufacturing has been shifted to Asia, while the U.S. retains the high-end, more capital-intensive production lines.

Our figures show that Seagate's geographic dispersion has led to a very high spatial concentration on Asia. We need, however, to add a second aspect: an extreme spatial concentration within East Asia. Let us start again with capacity figures. Slightly more than 92 percent of Seagate's capacity in Asia is concentrated in three locations: in Bangkok (almost 32 percent), Penang (more than 30 percent) and Singapore (a bit less than 30 percent). This may change, however, as Seagate is now beginning to expand into less congested and cheaper locations, including Korat/Thailand (currently with 6 percent of Seagate's Asian capacity), Shanghai/China, and Batam Island/Indonesia.

A similar picture of intensive geographic deepening within Asia emerges from Seagate's employment figures. Almost 50 percent (26,000 out of 55,000) of Seagate's Asian employment is concentrated in its plant in the outskirts of Bangkok, which clearly indicates that Bangkok is currently the center for low labor cost volume manufacturing. Next comes Singapore, with more than 27 percent (15,000), substantially more than Malaysia's 16 percent (9,000 people). With the share of employees per sq-ft is in Singapore much higher than elsewhere in the region, these figures nicely show that Singapore is increasingly taking on the role of a coordination center. An increasing share of this indirect labor force today is recruited on the international labor market, and includes managers from the Philippines and India, and engineers from China, India, and many other countries. Finally, Penang's low ratio of employment relative to its share in Seagate's production capacity clearly indicates that Penang's production facilities have been rapidly automated and now include higher-end manufacturing activities such as component manufacturing.

Over time, Seagate has developed a quite articulate regional division of labor in East Asia. Bottom-end work is done in Indonesia. Malaysian and Thai plants make components and specialize in partial assembly. Singapore is the center of gravity of this regional production network: its focus is on higher-end products and some important coordination and support functions. It completes the regional production network, by adding testing, which requires precision.

Let us now look at the broader picture and see how Seagate's Asian activities fit into the company's worldwide production network. Today, Seagate's international production network consists of four main components: (1) final assembly and test operations of disk drives; (2) sub-assembly and component manufacturing; (3) external sourcing of components and sub-assemblies; and (4) product and component development, proto-typing, and initial process engineering.

(1) Final assembly and test operations of disk drives

Seagate has designated the following locations for these activities:

- Singapore is responsible for developing volume production processes and test software. It also hosts final drive assembly across the whole gamut of drives (from 1.8" to 5.25").
- Bangkok/Thailand has become the prime center for volume manufacturing. It concentrates on the final assembly of lower-end drives and gradually upgrades into mid-level and higher-end drives.
- In the U.S., Bloomington/Minnesota and Oklahoma retain some final assembly and testing activities, primarily for higher-end drives for mainframes and servers.
- Clonmel in Ireland is responsible for the assembly of high-speed 3.5" drives.

In short, there is a clear division of labor between different assembly locations: Oklahoma and Bloomington concentrate on leading-edge drives, Clonmel/Ireland produces high-end drives for the European market, while volume manufacturing has been moved almost exclusively to Asia.

(2) Sub-assembly and component manufacturing

Compared to final assembly, subassembly and component manufacturing have been less prone to geographic dispersion. Most of the higher-value added activities remain firmly entrenched in the U.S., although some activities have been moved to Europe. For example, Seagate Magnetics, the affiliate that produces media, has concentrated all production in California. And wafer fabrication, a core process of head manufacturing, is concentrated in Minnesota, as is automatic slider fabrication for MR heads.

Key components and complex production processes have thus been quite resistant to geographic dispersion beyond the boundaries of a few highly specialized regions, notably Bloomington and Minneapolis (both in Minnesota), and California.

In Asia, Penang/Malaysia has become Seagate's prime component manufacturing center. In addition to head-gimbal assembly (which is a mature technology), this affiliate is also reported to host the production of MR Heads.[106] If true, this would be a perplexing development. MR

[106] Seagate Profile, compiled by Allen Hicken, November 6, 1995.

head manufacturing is the most complex technology in the HDD industry today. It requires very high levels of automation, requiring some of the electronics industry's most complex and costly equipment. In addition, key process variables are poorly understood, resulting in frequent process disruptions (down-times) and very low yields. Moreover, MR head production is characterized by extreme investment thresholds and very demanding requirements for support services. It is thus very difficult to understand why Seagate would want to transfer such a highly unstable technology to Penang.

There is in fact strong evidence to support such skepticism. Most likely Penang will produce the lower-end stages of MR head manufacturing, i.e. head-gimbal and head-suspension assembly and testing. This is especially likely as Seagate recently started a massive recruitment campaign that would enable it to concentrate the complex stages of MR head manufacturing in Minneapolis (wafer fabrication and slider fabrication).[107] Seagate has placed job adds in all major electronics journals and has been heavily recruiting manufacturing automation engineers.[108] More specifically, Seagate is searching for mechanical manufacturing automation engineers that can "develop an automated process for slider recording head fabrication." Slider fabrication is the core of MR head production and requires extreme automation. Obviously, Seagate has made a strategic decision to catch up in factory automation. While IBM's heavy reliance on factory automation was extremely costly at the outset, it enabled IBM to become the industry leader. As a result, IBM is now in a much better position than Seagate to reap premium prices and thus profit from the current shortage of MR heads.

It is also important to note that, for subassembly and component manufacturing, locational patterns differ considerably across product and market segment. Bangkok is active in head & arm stacks, spindle and stepper motors, and shares head-gimbal assembly at the Korat

[107] Wafer fabrication is the first step in the manufacture of inductive thin film heads. It is an extremely complex technology that requires very expensive equipment and the mastery of complex process technologies. Inductive heads are produced with manufacturing processes adapted from semiconductor manufacturing operations. Thin films of highly permeable magnetic material are deposited on a non-magnetic substrate to form the magnetic core, and electrical coils are electroplated in a pattern which has been imprinted through photolithographic techniques. The next step required to produce thin-film heads is slider fabrication , i.e. to machine or slice wafers. The machining process is accomplished in four phases. First, diamond saws cut the wafer into rows, or bars, of sliders. Second, the rows are lapped to the proper throat height using an automated, multi-stage lapping process. Third, the companies use a variety of processes to define and shape the air bearing surfaces of the individual sliders in each row. And finally, the rows are cut into individual sliders. Approximately 8400 individual sliders (not considering actual yields) can be produced from one six inch wafer. Based on David McKendrick, Profile of Suppliers of the HDD Industry: Media and Heads, June 21, 1996.

[108] See, for instance, Seagate's job add in *Datastorage*, March, 1996.

plant. Singapore produces printed circuit boards, while Indonesia's Batam island does low-end PCB assembly and basic subcomponent assembly.

(3) External sourcing of components and sub-assemblies

While Seagate has a reputation for high vertical integration,[109] it nevertheless has to procure a large number of components and sub-assemblies from outside sources. Seagate has experienced a rapid geographic dispersion for these activities. It procures components and sub-assemblies from independent suppliers located in the U.S., Europe, as well as Asia, although leading-edge products are still predominantly sourced from the U.S. and Europe. Within Asia, major suppliers include Japanese firms and their affiliates in East Asia, and firms from Korea, Taiwan, Singapore, Hong Kong, Thailand, and the Philippines. This clearly indicates that Seagate's component sourcing today extends well beyond the boundaries of Southeast Asia.

(4) Product and component development, proto-typing and initial process engineering

Almost all of these activities remain concentrated in four locations, all of them located in the U.S.:

- Scotts Valley and Simi Valley (both in California) are responsible for the development of 3.5 inch, 2.5 inch, and smaller form factor drives for desktop, laptop, notebook, and sub-notebook computers.
- Oklahoma City concentrates on the development of 3.5 inch drives for use in minicomputers, super-minis, work stations, and file servers.
- Bloomington, Minnesota is responsible for 3.5 inch and 5.25 inch drives for use in systems ranging from work stations to supercomputers, as well as for new markets such as digital video and video-on-demand.

4. Divergent Approaches to Geographic Dispersion

It is important to realize that American computer companies have pursued very different approaches to geographic dispersion and that they differ quite substantially in how they have developed their Asian production networks. Seagate's heavy reliance on intra-firm production networks is one important example, but it is in no way representative for other American producers of PC-related products. In order to demonstrate this diversity of approaches, we will consider two additional examples. The first, Apple Computer, moved to Singapore one year before Seagate, but has not bothered to increase the number of its Asian affiliates since then. Instead, Apple is known for its heavy reliance on out-sourcing. Our second example, IBM Storage System Division (IBM-SSD) has only very recently begun to establish export platform

[109] See Christensen [1993].

production lines in Asia. As we will see in both cases, peculiar features of strategy and structure have shaped their approach to geographic dispersion, as have particular features of their product mix.

4.1. A Heavy Reliance on Outsourcing: The Case of Apple Computer

It is important to understand that Apple's move to Singapore in 1981 took place at a time when its main product was still the Apple II, a no-frills, low cost computer box that was meant to establish the "personal computer" as an alternative computing paradigm to IBM's centralized main frame computers. In order to establish Apples design as the de facto standard, the focus was on cost leadership and speed-to-market. Thus, Apple focused on its core competence in design and marketing, while outsourcing most of the components.[110] In 1982, for instance, board stuffing was done by a contract manufacturer based in San Jose, CA, Floppy Disk Drives (FDDs) were sourced from Shugart and Alps, HDDs were procured from Seagate, Mostek, Synertek, and NEC provided RAM and ROM memory chips, and monitors were purchased from Sanyo. Final assembly was done in California, Texas, Ireland, and Singapore.[111]

IBMs successful entry into the PC market followed a similar pattern. Time-to-market was critical, with the result that IBM's PC division was established as a quasi-independent business unit that was able to bypass IBMs cumbersome system of bureaucratic control and its rigid internal procurement procedures.[112] As a result, all parts were put up for competitive bids from outside suppliers and a wide range of firms provided particular components to IBM: HDDs were provided by Tandon, power supplies by Zenith, motherboards by SCI Systems, and printers by Epson (Langlois [1992], p. 23). The IBM PC was designed as an open box ready for expansion, reconfiguration, and continuous upgrading, which gave rise to the rapid spread of IBM PC cloners.

Apple's response to these new challenges was an attempt to reestablish its leadership position based on a closed proprietary system. After some disastrous failures (Apple III and

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110 "Our business was designing, educating and marketing. I thought that Apple should do the least amount of work that it could and that it should... let the subcontractors have the problems." Mike Scott, Apple`s president in 1982, as quoted in Moritz [1984], p. 200-201.

111 Based on Langlois [1992], p. 17, note 44.

112 In an article published in 1989, Ralph Gomory, IBMs former head of R&D, demonstrated how the "cyclic development" process had changed the requirements of innovation management. As competition increasingly centers on price and speed-to-market, computer companies need to launch products again and again with incremental improvements in a shorter product cycle. The result is that time-to-market overrides most other concerns. See Gomory [1989].

Liza), these attempts finally culminated in the introduction of the Macintosh brand. The shift to Macintosh resulted from a belated recognition by Apple's management that, in terms of cost leadership, it could not compete with IBM and even less so with the myriad of newly emerging IBM PC cloners. Apple thus made a strategic decision to focus on its core competency in developing a user friendly operating system and advanced desktop publishing functions.[113] For quite some time, this strategy enabled Apple to engage in hefty premium pricing, with the result that its margins were well above the industry average.

As a result, Apple decided that it would not make sense to try to establish its own intra-firm international production network. Instead, the company increased even further its reliance on outsourcing and contract manufacturing. While this strategy worked well for quite some time, it is also probably the main root cause for Apple's current crisis. Indeed, because of its heavy reliance on outsourcing, Apple was struck with severe periodic shortages of key components which caused delays in new product introduction and heavy price increases--the key problems facing the company today.

What matters for our purposes is that Apple's strategic focus has shaped its approach to geographic dispersion. This leads to a quite peculiar situation: while its markets became highly globalized, Apple did not expand its proprietary international production network. By the early 1990's, roughly 45 percent of Apple's sales revenues were generated outside the U.S., with 30 percent in Europe, and the so-called ROW (rest of the world), most of it Asia, including Japan, generating another 15 percent.[114]

At the same time, roughly 30 percent of its total revenues came from products manufactured in a different region from which they were sold. This appears to indicate a relatively high level of geographic dispersion of its production activities. This share was even higher for products sold in Asia, where 35 percent of the products sold originated from outside the region (30 percent from the U.S. and 5 percent from Europe.)

A closer look, however, shows the importance of outsourcing. As we have seen, 65 percent of the products sold by Apple in Asia have been produced within the region. Out of these, however, only 40 percent came from Apple's subsidiary in Singapore, while 25 percent

[113] Both technologies had been developed way back in the 1970's at the Xerox research laboratories in Palo Alto. In one of the greatest blunders in computer history, Xerox' top managment refused to invest in these technologies, with the result that Steve Jobs, one of Apple co-founders, was able to acquire them at almost no cost.
[114] These and other figures on Apple's situation in the early 1990's are taken from Levy [1994, 1995].

came from independent OEM suppliers. It is striking to see that, in terms of the number of Apple affiliates, nothing has changed since the early 1980's. Ten years later, Apple still continues to rely on the same three production sites: Fremont/California, Singapore and Cork/Ireland. Despite the rapid growth of the PC industry, Apple has not added any new affiliates. Instead, it prefers to increase its reliance on subcontracting and OEM contracts. For instance, one of the earlier models of the Macintosh Powerbook was produced by Sony as part of an OEM contract. Apple is also a major OEM customer of Taiwanese PC vendors.[115]

Apple's product mix is also shaped by its approach to geographic dispersion. Apple produces products that heavily depend on time-to-market and efficient order fulfillment. In order to reduce the risk of disruption, the company relies heavily on dual sourcing: most systems are sourced from two of its facilities. Each manufacturing site performs two identical operations: PCB assembly (stuffing boards with components) and system assembly (combining PCBs with other components, such as power supply, disk drives, etc.)

Over time, the division of labor between these different production sites has developed in a fairly predictable manner, at least until the recent shake-up of the company. Until the early 1990's, Apple's three sites were neatly distinguished by their product and market focus, their product mix, and the role that each of them played in the introduction of new products. Fremont focused on newer, higher-end products and was primarily responsible for moving a motherboard through the prototype and pilot stages. Singapore focused on high volume, lower-end products. Cork/Ireland focused primarily on the European market, but also acted as a buffer and second source for other products. In 1990, Fremont had a substantially greater volume and range of products than Singapore: it assembled thirty to forty different boards, while the Singaporean plant handled only about twelve.

This pattern has become blurred as shorter product cycles have forced Apple to shift production of new products to Singapore right from their initial market introduction.[116] In addition, due to an increasingly severe profit squeeze, Apple has been forced to increasingly shift volume manufacturing to Singapore and further increase its reliance on OEM contracts.

Overall, Apple's shift to international production appears to have remained truncated, i.e. stuck half way between partial and more systemic forms of globalization. For instance, Apple

[115] For details, see Ernst, [1997a].
[116] See also the discussion in chp. IV below.

has experimented with alternative patterns of specialization. For some products, pilot projects were run where PCB assembly was located in Singapore only, with PCBs then flown to the U.S. for final system assembly. This obviously constituted an attempt to copy Hewlett Packard's concept of "delayed product differentiation," by shifting final assembly of finished systems close to the final customers.[117] This would have enabled Apple to customize products more quickly to the changing requirements of final customers. The experiment was not to last, however. With Apple considering the system too complex and thus too risky, it was soon discontinued. Arguably, this has been a result of Apple's heavy reliance on outsourcing and the short-term nature of its links to outside suppliers.

4.2. A Late Shift to Asia: Geographic Dispersion at IBM's Storage System Division

The approach of IBM's Storage Systems Division (IBM-SSD), located in San Jose, CA, to geographic dispersion is shaped by its long history as a captive supplier, with a product mix strongly biased toward mainframe computers. Until July 1990, the storage division had to report to IBM's mainframe group, and most of its products were sold in-house.

In 1991, IBM-SSD controlled almost 21 percent of the $53 billion worldwide storage-related products market. With sales revenues of $11 billion, it was nearly as big as IBM's $14 billion workstation business.[118] Due to its heavy focus on mainframe storage products, IBM at that time still considered Fujitsu and Hitachi, each of them with less than $1.5 billion in annual disk drive sales, to be its closest storage competitors. Very little benchmarking took place with independent drive manufacturers like Seagate, Maxtor and Conner that sold primarily to PC manufacturers.

As part of drastic changes in the organization and strategy that affected all parts of the giant corporation, IBM-SSD was transformed into an independent business unit in December of 1991. The storage division shared this fate with IBM Microelectronics (New Jersey), which was also forced to shift to open market sales.

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[117] I will discuss this concept in detail in chp. IV below.
[118] Sales revenues, as reported in *Computerworld*, December 9, 1991. Note that, due to changes in the product classification scheme, this figure cannot be compared with later revenue figures. In 1993, IBM changed the product classification that it uses for reporting sales revenues. According to this new classification, sales revenues for storage products in 1991 were $7.2 billion, and fell to $6.3 billion in 1992 and $5.1 billion in 1993. However, these figures clearly indicate why IBM-SSD had to aggressively expand its open-market sales.

The move to open market sales dates back to 1984 when IBM sold modified IBM 3380 and IBM 3390 drives to Siemens and Bull HN Information Systems, along with modified IBM 3480 tape drives to DEC.[119] Until very recently, IBM's open market sales were thus restricted to high-end disk products required for mainframe computers, and it remained absent from the mass markets for low-end and mid-range disk products.[120] This began to change only in 1991, when IBM began test-marketing OEM sales of low-end disk drives.

It is thus fair to say that IBM-SSD has moved only reluctantly beyond its traditional role as a captive producer. This has had important negative consequences. While the storage group's products were supposed to span the entire range of IBM computer products, the fact that it had to report to the mainframe group led to a considerable bias towards mainframe storage products. Arguably, this also gave rise to a fairly conservative approach to product development, with the result that new products and component innovations relevant for down-sized computer systems were frequently introduced much later than by independent merchant drive manufacturers.

Take the example of thin-film head technology.[121] IBM had spent over $300 million to develop this technology. Pioneering research, underway at IBM laboratories in Yorktown Heights/N.Y. and San Jose/CA (Almaden Labs) since 1965, had proven the feasibility of this concept. IBM was thus the first firm to introduce thin film heads to its highly successful mainframe model 3370 in 1979. However, with IBM research reducing the uncertainty and risks for potential followers, other HDD firms quickly adopted the technology. As a result, IBM was the last firm in the industry to use thin film heads broadly in its entire product line. Likewise, although IBM spent over $100 million developing thin-film disks, it did not use them in any commercial product until 1988, well after most independent merchant drive manufacturers had done so.

The main cause has been IBM's attempt to protect its dominance by exercising tight control over its proprietary advanced componentry. In order to reap premium prices on its high-

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[119] The following discussion of IBMs belated move into open market sales is based on an interview with Charles Haggerty, vice president of IBMs OEM storage products division, in Computerworld, Vol. 25, No. 49 (December 9, 1991), p. 93.

[120] IBMs storage division's weakness in low-end and mid-range disk products gave rise to a rather peculiar situation during the mid-1980s: IBM was the largest buyer of OEM drives in the world and played an important catalytic role in the geographic dispersion of the disk drive industry. IBMs PC division was primarily responsible for this heavy reliance on outsourcing. Arguably, this gave rise to a vicious circle, perpetuating the weakness of IBMs storage division, especially in low-end products.

[121] For details, see Mark Geenen, "MR Heads Meet Thin Film Challenge," CTR, 14/7, Charles T. Clark, , "Data Storage Making Technological Leaps", *Digital News & Review*, November 21, 1994, and Christensen [1993].

end drives, sophisticated componentry was normally used only in high-end drives. As a result, although IBM was the first to introduce most of the key components required for HDD production, IBM was arguably the slowest to incorporate them across the spectrum of its product lines.

Of equal importance are some consequences for IBM's approach to geographic dispersion. As long as IBM's storage division was exclusively a captive supplier, it also had a very limited exposure to international production. Thus, until late 1991, IBM's storage division only controlled three U.S. factories, San Jose/CA, Rochester/MN, and Tucson/AZ. It had no control over the five overseas storage production sites, of which the most important were two in Europe (Havant/U.K. and Mainz/Germany) and one in Japan (Fujisawa/Kanagawa Prefecture).

IBM-SSD's shift to open market sales acted as a powerful catalyst for changing IBM's approach to international production. This led to fundamental changes in the geographic location of production. Belatedly, IBM began to copy the Seagate model and has moved final assembly and testing and some limited subassembly and component manufacturing to Singapore, Thailand and Hungary. This has led to far-reaching changes in the role played by the headquarters in San Jose, by IBM Japan and its European affiliates. Today, IBM-SSD in San Jose controls all IBM storage facilities worldwide.

Meanwhile, four years down the road, important changes have occurred in the organization of IBM-SSD's international production network. Almost all drive assembly and testing has been moved from the traditional locations in the U.S., Europe, and Japan to three new locations:

In Asia, Thailand (Saha Union Corp.) acts as a contract manufacturer and focuses on low-capacity disk drives, while a 100 percent-owned affiliate in Singapore concentrates on high-end drives (including those for servers and work stations) and coordinates SSD's production, procurement, and shipping activities within the region.[122]

In Europe, IBM-SSD's German operation in Mainz appears to have acted as a "home base" for the new facility in Hungary (located 45 miles southwest of Budapest), which is

[122] It is unclear what this implies for the role of IBM Japan which had initiated the arrangement in Thailand. For instance, will IBM Japan retain the role as a regional coordination center, or will this role be assumed by IBM-SSD's Singapore affiliate?

expected to assemble and test high-end drives (1.2GB and 1.7GB 3.5" drives from IBM's Deskstar family).[123]

In Latin America, there are indications that IBM Mexico (Guadalajara) will take on some subassembly and final assembly activities.

Compared to the leading independent drive manufacturers, IBM-SSD not only started very late with its shift to international production, but the scope and depth of its international production network is quite limited. Drive assembly and testing clearly has moved out of the traditional production centers in the U.S., Europe, and Japan. Increasingly, they are likely to be consolidated in Singapore, Thailand, and Hungary. Also, an increasing variety of sub-assembly activities, such as head suspension assembly, has started to move to some of these new locations, including Mexico. The same is true for sales, marketing, and production-related support services, including preventive maintenance, training, and quality management. However, very little component manufacturing appears to have shifted abroad, and important key components, notably heads and disks, continue to be manufactured in San Jose/CA and Mainz/Germany.

All the core activities of R&D have remained centralized in a few locations (mainly in San Jose/CA, Yorktown Heights/N.Y., Fujisawa province/Japan, and Mainz/Germany) that were traditionally the main centers for storage-related innovations. This appears to apply to product and component development as well as to proto-typing and initial process engineering. This high geographic concentration of R&D is unlikely to change any time soon, reflecting IBM-SSDs heritage as a captive producer. Mainz/Germany, for example, remains the center of excellence for automated slider fabrication, a key process for MR head production.[124]

It is important to note that IBM-SSD has so far remained quite cautious and reluctant in its move to overseas production. This applies both to the scope of activities that have been moved abroad as well as to the product mix. In contrast to independent drive manufacturers, the international production network of IBM-SSD so far seems to be characterized by a considerably more narrow international division of labor, both in terms of geographic dispersion and product coverage. Its international division of labor also appears to be more shallow in terms of the value-added overseas.

[123] AP via NewsPage, November 21, 1995, courtesy Roger Bohn.
[124] Author's interview at IBM-SSD, San Jose, CA, December 1995.

The main reason, in my view, is that IBM-SSD could not start from scratch like Seagate and others, but had to build on a fairly sophisticated, yet limited international production network that existed before to serve IBM's captive storage needs. By moving to open market sales, the organization of this new production network was driven by a very different logic than the old captive supply-based network. This indicates that there is a drastic need for change. Implementing such change, however, is constrained by sunk investment, organizational procedures, and behavioral patterns characteristic of the old, captive IBM production system. In other words, changing the "traditional IBM way of doing things" may be much more difficult than top management may currently perceive. The heritage of IBM-SSD's closed production system is well and alive. IBM-SSD still has to learn how to manage an international production network that is geared to open market sales.

5. The Ascent of Japanese International Production Networks

Let us now turn to another case where the heritage of a closed production system has constrained the development of geographic dispersion--the experience of integrated Japanese electronics companies. Most of their international production activities originally were concerned with by-passing import restrictions. Such investments started first in Asia, with the spread of mini-Matsushitas in almost all countries of the region dating back to the early 1960's. Starting from the mid-1970's, the focus then shifted to the American market, and increasingly also to the European market.

5.1. The Move to East Asia

It was the catalytic effect of the Yen appreciation around 1986 that led to the well known expansion of Japanese international production networks into East Asia.[125] Over time, the focus of such investments has shifted twice: first, from Northeast Asia (Korea, Taiwan, and Hong Kong) to the ASEAN region (primarily Singapore, Malaysia, and Thailand); and, second, beginning around 1992, from the ASEAN region to China, Indonesia, the Philippines, and Vietnam. In a very short period of time, Japanese electronics firms have thus substantially extended the geographic coverage of their East Asian production activities. At the same time,

[125] This process has been documented in detail in Ernst [1997b]. See also Ernst [1994c, 1997c].

there are signs of an emerging regional division of labor even as Japanese firms make serious efforts to integrate their Asian production networks into their global strategies.

The result is that that Asia has dramatically increased in importance as Japan's global manufacturing base. In 1988, the region accounted for roughly two thirds of the total number of overseas investments of Japanese manufacturing companies. Five years later, by 1993, this share had shot up to more than 90 percent.[126] Much of this investment has moved into China, becoming one of the main driving forces behind the "China fever" that raged through the Japanese industry during the early 1990's.

The electronics industry has clearly been the main driving force behind this shift to Asia. Between 1985 and 1993, nearly one half of the total increase of Japanese manufacturing FDI in East Asia went into electronics.[127] By 1993, almost 60 percent of all foreign affiliates of Japanese electronics firms were located in East Asia.[128] This share was even higher for employment. In 1993, 70 percent of the overseas employment of Japanese electronics firms was in East Asia. Compared to North America and Europe, East Asia obviously attracted relatively more labor-intensive investments.

5.2. Changes in the Locational Patterns: Towards a Regional Specialization

At the same time, important changes have occurred in the locational patterns of such investments. As long as the focus was on domestic markets, the investments of Japanese electronics firms were widely dispersed across Asia. Once the focus shifted to export-platform production, however, Japanese electronics firms concentrated most of their investment in a handful of industrial sites in Malaysia, Taiwan, Singapore, and Thailand. In 1993, these four countries accounted for two-thirds of all Japanese affiliates in Asia; Malaysia had the highest share (24 percent), followed by Taiwan (17 percent), Singapore (13 percent) and Thailand (12 percent).[129] During the same year, 70 percent of the overseas employment of Japanese electronics firms was concentrated in Asia; Malaysia alone accounts for 30 percent of total overseas employment of Japanese electronics firms.

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[126] JETRO [1995], p. 20.
[127] Yoshitomi [1994], p. 16.
[128] BRIE Database on FDI and International Production Networks, computed from data in Nihon Desnhi Kikai Kogyokai (NDKK) [Japan Industry Association of Electronics], 1994 Kaigai Hojin Risuto [List of Overseas Coporations, Tokyo.
[129] Computed from data in Nihon Denshi Kikai Kogyokai (NDKK), [Japan Industry Association of Electronics], 1994 Kaigai Hojin Risuto [List of Overseas Coporations, Tokyo.

Since the beginning of the 1990's, the pendulum has swung back to geographic widening, with the result that Japanese production networks in Asia are now much less geographically concentrated. Of greatest importance is that the share of China in the investment of Japanese electronics firms abroad has increased by leaps and bounds: from 0.6 percent in 1990 (the year after the Tienanmen massacre), it has now reached almost 7 percent, approaching the 7.7 percent of ASEAN.[130]

However, two important complementary changes have occurred which have remained largely unnoticed: (1) Japanese production lines and procurement links have been rapidly upgraded; and (2) Asian affiliates of Japanese component manufacturers, especially in Taiwan and South Korea, have also received a massive face-lift.[131]

A regional specialization is now beginning to emerge for Japanese networks in East Asia. In the electronics industry, we can distinguish the following broad pattern:[132] Singapore and Hong Kong compete for a position as regional headquarters (together with major support functions like procurement, testing, engineering services, and training); South Korea and Taiwan compete for OEM contracts and as suppliers of precision components; Malaysia and Thailand, and the Philippines are preferred locations for the volume production, especially of mid-level and some higher-end products; and China, Indonesia, and (possibly) Vietnam compete for low-end assembly and simple components manufacturing.[133]

While Japanese electronics firms have expanded and deepened their Asian production networks, American electronics firms did not sit idle. Since the early 1980's, they have rapidly expanded and deepened their links with suppliers in the region through an increasing variety of inter-firm supplier networks. At the forefront of these activities were the same four countries that also attracted Japanese firms, i.e. Singapore, Malaysia, Taiwan and Thailand. Both American and Japanese firms have thus concentrated, by and large, in the very same countries. For both, Singapore is often the apex, and performs critical support and coordination functions; Taiwan

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[130] MOF figures, as quoted in JETRO [1995], p. 17.

[131] This is basically due to the fact that MOF figures of Japanese FDI do not report reinvestments by overseas affiliates, nor do they provide a sufficiently fine-grained sectoral disaggregation. This is now changing as both the Export-Import Bank of Japan's Research Institute for International Investment and Development, and the most recent Overseas Investment Statistics Overview by MITI include such information. For an early pioneering contribution, see Tejima [1994].

[132] Of course, details differ for different sectors and product groups.

[133] In Vietnam, the pacesetter is Fujitsu, which established a printed circuit board assembly plant in early 1996. This plant could pave the way for further Japanese investments.

and South Korea are suppliers of precision components and OEM sources; and Malaysia and Thailand are the preferred location for volume manufacturing.[134]

There are, however, important exceptions. For instance, almost all leading Japanese disk drive manufacturers have shunned the established global production center, Singapore, and have instead chosen to establish their Asian supply base in the Philippines. One Japanese company, however, has not followed this pattern: Matsushita Kotobuki, an affiliate of the Matsushita group. This company, which has acted as the manufacturing arm of the American disk drive company Quantum since 1984, clearly illustrates that nationality of ownership, on its own, is not sufficient to explain why companies differ in their approaches to the organization of international production.

5.3. The Vintage Factor: Learning How to Manage International Production Networks

One important common feature of Japanese electronics firms is that they are still laggards in international production compared to their American and European counterparts. Until the mid-1980's, Japanese electronics firms had stubbornly resisted the shift to international production. For quite some time, they have tried to reap the maximum advantages from certain basic features of their domestic production system which they thought would be difficult to reproduce abroad.[135] The result is that today their overseas production ratios (OPRs) are, in general, much lower than their American and European counterparts. This is true even for early Japanese pioneers in international production. Even companies like Sanyo, Sony, and Matsushita, which among large and vertically integrated Japanese companies have arguably been most exposed to international production, have much lower OPRs than their European and American counterparts.[136]

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[134] Hong Kong's importance as an entry-point into the Chinese market as well as a coordination center for the expanding production networks in China has recently dramatically increased for Japanese and American electronics firms. For obvious reasons, it is difficult to get reliable data on these activities.

[135] For an excellent analysis of the rationale that has induced Japanese electronics firms to postpone overseas production, see Tachiki and Aoki [1991] and Tejima [1996].

[136] Sanyo's OPR is almost 34 percent while both Sony and Mastushita have an OPR of roughly 20 percent. For details, see Ernst [1997c]. We need to add, however, that overseas production ratios are typically much higher for small- and medium-sized Japanese electronics firms. This is true for smaller firms that produce final products but have a quite narrow product focus, like Aiwa (whose OPR exceeds 85 percent) or Uniden (with an OPR close to 100 percent). OPRs however are equally high for the hundreds of relatively small subcontractors and component suppliers which, as a result of the yen appreciation, had to move most of their production offshore, primarily to Southeast Asia and China. Typical for this category of firms is Showa Plastics, an Osaka-based producer of plastics

These figures are in contrast to the levels of international production that are typical for the leading American and European electronics firms. Today, American PC companies generate roughly 40 to 50 percent of their total production value in East Asia. Seagate, the current market leader for HDDs, is estimated to generate around 75 percent of its overall production value in East Asia, primarily in the triangle that comprises Singapore, Malaysia, and Thailand.

The long involvement in international production of European electronics multinationals has resulted in fairly high OPRs. Although until quite recently most of this overseas production has been focused on Europe, this is now beginning to change. All the major European electronics firms have recently discovered East Asia (exclusive of Japan) as a "primary investment priority" and have drastically increased their production and sourcing activities in the region.[137] We estimate that during the early 1990's, major European electronics firms generated roughly 15 to 20 percent of their total production value in Asia. Among these companies, Philips stands out as a pioneer in international production.[138] With 90 percent of total sales being generated abroad and 40 percent outside Europe, Philips had developed an extended and sophisticated international production network by the mid-1980's. By 1988, roughly one fourth of all Philips products were made in East Asia, as compared to 15 percent during the early 1980's.

The fact that firms differ in their exposure to international production, the so-called "vintage factor," plays an important role for some of the other features of international production networks that I discuss in chapter IV. In short, it simply takes time to develop the capacity to manage international production networks. We know from innovation theory that firms need time to develop their capabilities and that knowledge and capability formation is a path dependent process.[139] This is true for a variety of technological capabilities as well as for organizational capabilities. Time is of even greater importance for developing a firm's capacity to manage international production. Hence, the importance of the vintage factor. Stopford, for instance, argues that "... firms progress over time from the simplest to more complex forms [of international production networks] as they learn how to manage [them]." (Stopford [1995], p. 2) Such learning also takes place in the foreign affiliates: " As skills and resources accumulate within the various foreign units, new options and more complex projects can be undertaken

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casings: 95 percent of its 3000 employees work abroad, mostly in Singapore and other Southeast Asian countries. For details, see Ernst [1997].

[137] For evidence, see Lasserre and Schuette [1995].

[138] Philips profile, in the BRIE Database on FDI and International Production Networks.

[139] For a review of this literature, see Ernst, Mytelka and Ganiatsos [1997]

without relying heavily on the parent organization for help and guidance." (Stopford [1995], p. 16) I would add that similar learning processes also take place in those foreign firms that act as subcontractors and suppliers.[140]

Latecomers to international production are thus likely to differ in their organizational approaches from firms which have had a much longer learning experience. This is certainly true for Japanese firms. As latecomers to international production, they had to minimize risk and to organize their production networks in a highly centralized manner. American electronics firms, by contrast, have been exposed long enough to the uncertainties and vicissitudes of international production and thus should be able, *cum grano salis,* to develop more subtle and sophisticated organizational approaches.

It is important to keep this simple fact in mind in the study on the HDD industry. It indicates that, in the end, the choice of strategies may be much broader than the limited dichotomies that current policy debates would seem to indicate. Certainly, "either-or" propositions like "expanding offshore versus relocating-back-home" are not very helpful. They easily distract from the real issue: how American HDD firms can match an expansion of geographic dispersion with a continuous upgrading of their product mix and their domestic production system in the U.S.

5.4. Current Developments: Competing for Asia's Supply Base and Markets

Geographic dispersion of production in the electronics industry has occurred on a massive scale. Moreover, most of this expansion has occurred in a relatively short period of time. While originally much of this expansion was centered on Europe, with market access as the main motivation, the focus has now clearly shifted to East Asia.

So far, there has been very little over-lapping and rivalry between American and Japanese production networks in Asia. American firms focused on PC-related products while Japanese firms focused on consumer electronics and appliances. This is now rapidly changing. As Japanese firms shift a variety of PC-related products to East Asia, they may now try to tap into the same set of regional supplier networks and capability clusters that have so far catered

[140] For an analysis of the learning effects in such arrangements, see Poh Kam [1991], and Ernst [1994b].

primarily to the needs of American firms.[141] This implies that, for the first time, American and Japanese firms will have to compete for the same supply sources in East Asia.

In response to earlier investments of U.S. offshore assemblers in East Asia, a great variety of local suppliers and support industries have emerged since the mid-1970's. During the 1980's, the preemptive development of these East Asian supplier networks greatly helped American computer companies consolidate their market leadership.[142] It remains to be seen whether American computer companies will be able to retain control over these precious supplier networks now that Japanese PC vendors are also beginning to target them.

This raises a number of intriguing questions. How will this affect the strategies of U.S. firms? Will they be forced to expand their in-house component manufacturing activities in Asia, as Seagate does? Will they be forced to establish centralized control in order to keep a tighter rein on technology leakage which could potentially benefit their Japanese rivals? In other words, will the pendulum now swing back, after a long period of extended outsourcing, to more integrated forms of organizing the international production networks of American computer companies?[143] And how will this affect the approaches of American electronics towards their external suppliers and contract manufacturers? Will they be forced to establish longer-term links with local suppliers in order to establish effective control? Presumably, American firms have to act in order to prevent Japanese firms from developing East Asia into their exclusive supply base in the future.

Similar arguments can be made for the highly contested growth markets in East Asia, which may also imply substantial changes in the organization of the Asian production networks of U.S. firms.

Chapter IV: Increasing Complexity

1. Product Mix

Changes in the product mix of international production networks (i.e. in the maturity of the transferred products) are an important manifestation of increasing complexity. As conceptualized in the product life cycle (PLC) theory, international production traditionally

[141] For an in-depth analysis, see Ernst [1997b].
[142] For evidence, see Ernst and O'Connor [1992], especially chp. 2, and Ernst [1994].
[143] For an excellent analysis of the dialectics of outsourcing and integration in the hard disk drive industry, see Christensen [1995].

proceeded in a gradual manner. Production began to move overseas only once a product had reached a certain degree of maturity, while newer, leading-edge products normally remained confined to domestic production.[144]

In the HDD industry, for instance, new products used to be produced first in the U.S., mostly close to or on the premises of the parent company. Production was shifted overseas only when markets became sufficiently large to justify volume production. Once this stage had been reached, the move to overseas production typically displayed three characteristic features: (1) it followed a sequencing pattern that was strictly hierarchical in the sense that production moved top-down from higher-end to lower-end locations; (2) it was cumulative, in the sense that the order of sequencing could not be changed and production had to move from the original location L_1 (the U.S.) first to L_2 (mostly Singapore), before it was able to move on to L_3 (e.g. Malaysia or Thailand) and other lower-end locations; and (3) there was little scope to compress the period of time that needed to pass before production could move from one location to the next.

This is no longer the case today. There are a number of reasons why the "product life cycle theory" ceases to explain the pace and sequencing of international production. To start with, some of the basic assumptions of this theory that made perfect sense in the 1960's may have lost much of their validity today. The PLC theory is based on three assumptions: (1) production can move overseas only when design features and process specifications have been stabilized; (2) price competition would intensify only after a certain period; and (3) foreign markets would emerge only with a considerable time lag, after the original launch market had begun to blossom. None of these assumptions can be taken for granted any longer.

This is true for the computer industry as well as for the HDD industry. As we saw in chapter I, product cycles in both industries have been ruthlessly cut short and time-to-market has become the single most important determinant of competitive success. Neither PC vendors nor HDD companies can thus afford to follow the pace and sequencing patterns prescribed by the PLC theory. In short, they are forced to shift production overseas much earlier than predicted by the PLC theory. Simultaneously, they begin to deviate from the established rigid sequencing pattern.

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[144] For the core propositions, see Vernon [1966, 1979]. For critical assessments, see Cantwell [1995] and Ravenhill and Bernard [1995].

The following three examples illustrate the argument. The first example shows how shorter product cycles have accelerated the pace of redeployment of production overseas.[145] Traditionally, Apple started the production of new products in Fremont/CA. Production was transferred abroad only much later, after initial teething problems had been solved. Today, this incremental and sequential approach has become too costly and cumbersome. With product cycles dropping well below one year, it no longer makes any more sense to transfer production to Singapore one year after the launch of a new product. In order to amortize such investment, Apple must now shift production of new products to Singapore at the beginning of the product cycle.

The second example shows how the cutting of the product cycle has forced HDD firms to deviate from the established sequencing pattern.[146] Conner Peripherals (one of the HDD industry leaders before it was acquired by Seagate) has moved all high volume manufacturing abroad, with Singapore normally producing the most technically sophisticated products. Until recently, Singapore would work on advanced drives for a while, and then transfer them to another plant (usually in Penang/Malaysia). As product life cycles shrunk to nine and often even six months (for laptop drives, where Conner is especially strong), however, this was no longer possible. The result is that, once a particular product line is started in Singapore, it will remain there until the end of its life. Of course, this raises the question which products will be produced in Singapore and which ones will be produced in Penang, China, and elsewhere. In short, rather than being able to almost automatically follow a well-established pattern of locational sequencing, firms must now make a single locational choice. They need to assess their strengths and weaknesses and decide which competitive opportunities and challenges are most important.

The third example deals with Hewlett Packard, a company well known for its sophisticated management approaches. Early on, HP tried to break away from the rigid sequencing pattern of international production prescribed by the PLC theory. Indeed, by the mid-1980's, HP had already undertaken global production strategies in conflict with PLC prescriptions. For an unspecified office system product, HP simultaneously undertook basic research in one country, applied development in another country, volume manufacturing in two other countries, and first product launch occurred in an entirely different country.[147]

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[145] Levy [1994, 1995].
[146] Courtesy to Roger Bohn.
[147] Howells and Wood [1990], p. 178.

Instead of following the PLC sequencing pattern, HP prefers to define a worldwide product mandate for a particular location and then organizes its international production network around this particular center. Singapore, for instance, plays this role for two different products.[148] In 1993, Singapore received the worldwide product mandate for HP's DeskJet Portable printer brand. And one year later, in 1994, it became the worldwide product mandate location for Pentium servers which, by all standards, are fairly advanced products. Interestingly enough, the alternative location against which Singapore was benchmarked was not a U.S. location, but Grenoble/France. Singapore was perceived to have two advantages relative to Grenoble: (1) stronger process engineering capabilities, which are essential for servers; and (2) almost all component suppliers are located in close proximity, with casings in Singapore, power supplies in Thailand, and HDDs from Seagate (Singapore) or from Quantum/Matsushita Kotobuki (in Japan and Singapore). Probably the most striking feature of this arrangement, which shows how little explanatory value the PLC theory may currently have, is that by far the most important server markets are in the U.S. and in Europe. Nevertheless, HP decided to concentrate the production of Pentium servers in Singapore.

The shortening of the product life cycle is not the only reason why the PLC theory has ceased to explain the pace and the sequencing patterns of international production. Indeed, there are a number of additional reasons why electronics firms are forced to move the production of new products to East Asia early on in the product cycle.

First, it is no longer true that price competition only begins to heat up at a later stage of the product cycle. Since around 1991, severe price wars have swept across almost all sectors of the computer industry, and new products are no longer safe from these price wars. The result is that from the design phase on, firms are under tremendous pressure to reduce unit costs through economies of scale. This implies that firms must expand worldwide market shares at breakneck speed once the product has been launched. Frequently, this is impossible without relocating production overseas early on in the product cycle.

A second reason why firms are inclined to shift the production of new products overseas much earlier than before results from changes on the demand side. Most sectors of the electronics industry today are characterized by the huge windfall profits that a firm can reap from early market penetration. As we saw in chapter I, this is especially true for computer-related

[148] Hewlett Packard Profile, <u>BRIE Data Base on FDI and International Production Networks.</u>

products like HDDs. Survival thus depends on an early presence in the major launch market of this industry, which continues to be the U.S.

However, it is no longer sufficient to be first only in the U.S. market. In order to be a "global player," a firm must be able to introduce new products almost simultaneously in all major growth markets. This implies that Europe and Japan need to be penetrated at almost the same time as the U.S. market. In addition, new growth markets have emerged outside the Triad that also need to be penetrated early on. This is especially true for East Asia, which is an increasingly important growth market for the electronics industry.

Meanwhile, because electronics markets in Asia are still highly protected, market penetration in these countries requires an early shift to local production. This is true for consumer electronics, but even more so for computer-related products. While tariff barriers have been reduced, there are numerous non-tariff barriers which result from the existence of powerful domestic oligopolies that control domestic distribution channels. Indonesia and Thailand are obvious examples, but so are South Korea and Taiwan. With the exception of Hong Kong and Singapore, all countries in the region continue to protect their electronics markets. As a result, exports are no longer sufficient to guarantee an early penetration of these markets. Foreign firms are thus eager to establish a regional supply base in East Asia, and to match the size of production with the relevant size of this region's markets.[149]

There is no doubt that there are powerful reasons why electronics firms are forced to consider an early redeployment of production overseas. What needs to be explained, however, is why electronics firms are now able to ramp up production of new products in East Asia almost at the same time as in their home countries. There are a number of important enabling factors that have facilitated such an earlier transfer of production.

First of all, substantial improvements have occurred in the locational advantages of East Asian production sites. A number of East Asian countries have developed a variety of technological and organizational capabilities, with the result that they can now cost effectively design and produce most electronic hardware products. In addition, almost all of these countries now have sophisticated incentive systems for foreign investments.

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[149] This new focus on regional markets is reflected in the changing trade patterns of East Asia. See Ernst and Guerrieri [1997].

Technological change has acted as another crucial enabling factor that has facilitated an early transfer of the production of sophisticated products. The rapid diffusion of new information, communication and transport technologies have also played important roles. Likewise, reductions in the real cost of air freight has been essential for the movement of components and final products across national boundaries. In electronics, this is particular important as the segmentation of the value chain into multiple stages often causes components to transit the same national boundaries several times.

The telecommunications revolution enables swift and efficient transfer of information among the various nodes in a production network. With the help of computer-based information networks and management systems, electronics firms can now synchronize product development, marketing, production, and procurement across national boundaries and continents.[150] Much depends, of course, on whether the introduction of these technologies is accompanied by fundamental changes in the organization of production. There is a rich body of literature that shows that introducing technology without organizational change leads to a "productivity paradox": despite substantial investments in new technology, productivity may stagnate or even decline.[151] The crucial element, then, in the spread of international production networks are organizational innovations that enable firms to cope with the fast pace of change in markets and technology.

A second aspect is of crucial importance. Since the mid-1980's, fundamental changes in design methodology and the shift from metallic to plastic parts have facilitated the transfer of production of complex products to overseas locations.[152] Both developments have eroded the capacity of the "product life cycle" to explain the sequencing of international production. This finding runs counter to much of the established wisdom which argues that the spread of microelectronics and new materials will make it more difficult to transfer industrial production to developing countries. Nonetheless, four developments have enabled electronics firms to redeploy an increasing share of their electronics production early in the product cycle to East Asia:

(1) The shift from metallic to plastic parts has reduced the importance of precision mechanical engineering. While precision plastic injection molding is also a quite

[150] For details, see Ernst and D. O'Connor [1989].
[151] Important contributions are Avramovitz [1989], Freeman [1992], and David [1992].
[152] For interesting case studies on how both developments have enabled Japanese firms to ramp up quickly their huge export platform production facilities in Southeast Asia, see Kiba and Kodama [1991], Sunada, Toru et. al. [1993], and Kodama and Kiba [1994].

demanding technology, developing these capabilities in Malaysia and Thailand has been much easier than developing precision mechanical engineering capabilities. In addition, plastic parts are much lighter than metallic parts, and are thus much less costly to transport.

(2) The spread of standard ICs and printed circuit boards has led to a substantial reduction in the number of components. In turn, this has opened the floodgates for the current wave of OEM, ODM, and other contract manufacturing arrangements with an increasing number of local suppliers. Often, local affiliates of Japanese component suppliers have played an important catalytic role in the development of such local clusters of support industries.[153]

(3) As fewer components are required for a given product and as more the components are standardized, there is much greater scope for factory automation. The resultant shift to assembly automation (such as surface-mount technologies [SMT]) has reduced the number of assembly processes and the amount of inspection work required, which in turn has meant a substantial simplification of the production process.

(4) Finally, both the design and production of components have become increasingly automated. As a result, component producers are able to supply both high volume and small batch products at lower cost and at relatively short notice (due to a minimum of switching requirements). At the same time, yields and the quality of the components can be substantially improved, even with a work force that had not been exposed to a long tradition in mechanical engineering.

All of this is to say that electronics firms are now in a much better position to accelerate the transfer of production overseas, even for new and complex products. In short, the pace and sequencing of international production today no longer needs to follow the rules established by the PLC theory. Rather, both the pace and sequencing of international produced are shaped by firm strategies and their decisions on how to use international production in order to improve their competitive position. This, in turn, clearly adds to the complexity of international production.

2. Scope of Activities

A second dimension of increasing complexity relates to the scope of value chain activities that electronics firms are now decomposing across national borders.

Table 1 distinguishes six stages of the value chain. It ranks activities according to the ease with which they can be spatially dispersed. The more resistant an activity is to geographical dispersion, the more demanding are its requirements for local capabilities in the overseas location.

[153] For a collection of interesting case studies, see Mukoyama [1996].

Table 1: Stages of the Value Chain

(1) Sales & marketing (including the establishment of distribution channels and customer support).
(2) Final assembly and testing.
(3) Procurement (IPOs, consignment assembly, OEM/ODM arrangements, and "turnkey" production arrangements).
(4) Component manufacturing and sub-assemblies.
(5) Engineering (especially product customization and detailed process engineering).
(6) R&D (especially product and component development, proto-typing, and initial process engineering).

International production typically is preceded by the establishment of sales affiliates and distribution channels, the first of our six value chain activities. This is especially true for computer-related products. Almost without exception, local computer markets in Asia are heavily protected, and thus are difficult to penetrate.[154] Foreign companies are unlikely to succeed without powerful local joint venture partners that can guarantee access to distribution channels. Penetrating these markets normally involves three steps. First, the foreign computer company establishes sales and marketing joint ventures which, if successful, will be followed by consignment assembly by a local company. Only if these first two phases are successful will the foreign company consider investing in its own manufacturing affiliate. This gradual approach reduces the risk of international production and balances the limited resources available with the need to match production sites with major potential growth markets.[155]

Let us now move to manufacturing proper. Traditional forms of international production used to focus primarily on the selective redeployment of labor-intensive stages of assembly-type manufacturing and on some upstream activities, especially the processing of raw materials. This type of international production had a very narrow scope. It did not include high value-added manufacturing activities, including the production of key components. Nor did it involve essential support activities, such as R&D and product development, which remained concentrated at home.

In the electronics industry, two typical examples of this pattern are the earlier rounds of offshore chip assembly in Asia by American semiconductor merchant firms and the

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[154] The only exceptions are Hong Kong and Singapore.
[155] Author's interviews at Taiwanese PC companies, June 1995.

redeployment, starting in the mid-1980's, of consumer appliances to Southeast Asia by Japanese electronics firms. For quite some time, both approaches were characterized by a limited scope of the transferred activities.[156]

Offshore chip assembly at that time was the poor relation of the glamorous wafer fabrication. Called the back-end of the industry, it required cheap assembly hands (almost all young women), and very little else.[157] As for the first wave of export platform production of Japanese electronics firms, there is a widespread consensus that, apart from simple operational capabilities required for production and maintenance, very limited additional capabilities have been transferred.[158]

3. The Migration of Key Support Functions: A Misplaced Focus on R&D

This pattern is now beginning to change. Today, internationalization extends well beyond the sphere of labor-intensive manufacturing and covers an increasing variety of higher value-added activities. This is true even for locations outside the Triad, with some growth poles in East Asia obviously playing an important pacesetter role. As we will see in a moment, once manufacturing moves overseas, this often leads to a subsequent migration of key support functions.

Most of the debates on this issue have focused on the role of R&D, but this may be too narrow a focus. Indeed, there is sufficient evidence to show that internationalization of R&D lags far behind the internationalization of production and other value chain activities.[159] It is equally well accepted that international production may create very limited opportunities for host countries to develop core research and technological capabilities.

Posing the problem in such a way may well be misleading. Much of the literature associates innovation with the kind of activity undertaken by firms at the frontier. However, empirical research has shown that a majority of advances in technology result from activities which are not covered by the conventional definition of R&D (the definition used in the OECD Frascati Manual). Nelson, for instance, has emphasized the role of design and production

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[156] For evidence on semiconductors, see Ernst [1983]; for Japanese electronics firms, see Ernst [1994c, 1997b, 1997c].
[157] For detailed case studies, see Lim [1978] and Ernst [1983].
[158] For evidence, see Ernst [1994c], p. 18 passim.
[159] Important contributions include Cordell [1971], Pearce [1989], Pearce and Singh [1992], Pisano and Wheelwright [1995], and Chesnais [1992, 1994]. For overviews, see Granstrand, Hakanson and Sjoelander [1993] and Archibugi and Pianta [1996].

engineering for product and process innovation.[160] In a number of industries, however, both of these processes are not counted as R&D.[161] Despite these definitional issues, von Hippel has painstakingly documented that, in a wide range of industries, most innovations are developed by users and later adopted by manufacturers.[162] In other words, "... organized free-standing R&D is an important part of the investment and organization involved in advancing technology in many industries. However, it seldom accounts for all of that effort, and in a number of industries it accounts for only a relatively small share."[163]

It thus makes perfect sense to cast the net wider and to define <u>innovation</u> as "... the processes by which firms master and implement the design and production of goods and services that are new to them, irrespective of whether or not they are new to their competitors--domestic and foreign. Most of the time, and in most industries, innovation is based on the continuous and incremental upgrading of existing technologies or on new combinations of them."[164]

Two bodies of research clearly indicate that, once manufacturing moves, it frequently carries along a variety of high value-added support activities. Even if these activities do not involve formal R&D, they may still give rise to considerable learning and innovation. One such body of research inquires how the spread of production networks in Scandinavia has led to a bottom-up, evolutionary development of learning and innovative capabilities. According to these authors, such bottom-up learning processes explain why small Scandinavian countries, with their limited R&D resources, can still out-compete some of their much larger competitors. Hakansson [1990, p. 260] observes that "...foreign manufacturing units, originally set up as mere market outlets, in time acquire their own technical, managerial and marketing expertise. Thus, engineering capabilities acquired to perform routine technical activities--service, maintenance and customization of products to individual buyer needs--often evolve into proper R&D." Hakansson concludes that "... there is an almost irresistible creepage from production engineering upstream into design and development." (Hakansson [1990], p. 260)

There is a second body of literature that clearly demonstrates that international production can well lead to a migration of key support activities, even if there is no official

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[160] Nelson [1990a].
[161] The most prominent example is the car industry. In the garments industry, fashion design and the make-up of samples, which are essential elements of product innovation, are also not treated as part of the R&D process.
[162] Von Hippel [1988], in particular chps. 8 and 9.
[163] Nelson [1990a], p. 40.
[164] Ernst, Mytelka and Ganiatsos [1997].

transfer of R&D. This literature is focused on East Asia and shows how the spread of international subcontracting in this region has been conducive to the development of technological capabilities that today extend well beyond the sphere of manufacturing and include a variety of process and product development capabilities.[165]

Following a tradition established by Nelson and Winter [1982], this research focuses on learning and capability formation. An important finding is that indirect forms of technology diffusion play a more important role than direct and deliberate transfer of technology activities by multinational enterprises. For subcontracting arrangements, for instance, three indirect forms of technology diffusion can be distinguished:[166]

> (1) Learning facilitation which results from the exposure of the local subcontractor to the foreign buyer's qualification process, including testing and diagnostic feedback on quality and other dimensions of the performance of the supplier's products, the sourcing of technical experts to solve specific technical problems encountered by the supplier, and advanced indications on future quality/performance /feature requirements and targets.
> (2) Knowledge spillover effects which include product design specification and performance requirements, early supplier involvement in prototype development, access to technical and marketing information on competitors' products, informal sharing of technical information and ideas among the technical staff of both companies, and exposure to the foreign company's system of managing production and R&D.
> (3) Investment inducement which relates to investments in the formation of technological capabilities which the local supplier can only undertake because the subcontracting relationship reduces the perceived risk of such investments through a procurement commitment by the foreign company. This is true because the foreign company provides a stable source of income to finance the investment, in addition to access to superior market information that may reduce the risks involved in the investment decision.

In what follows, I present a few illustrative examples from various sectors of the electronics industry to show how electronics firms have, over time, shifted increasingly complex activities abroad, how this has led to a concomitant transfer of key support functions, and how this has in turn led to the formation of local capabilities. Section 4 describes how American semiconductor firms have contributed to a migration of support activities through their reliance on subcontracting arrangements. Section 5 presents evidence for Japanese electronics firms, while section 6 documents the spread of outsourcing arrangements in the computer industry. Section 7 analyzes two factors that are conducive for the joint migration of key support functions overseas: the systemic rationalization of international production networks and the role of proximity. The

[165] See Ernst and O'Connor [1989], Poh Kam [1991], Ernst [1994a], and Ernst, Gantiatsos and Mytelka [1997].
[166] Poh Kam [1991], p. 15.

result is that once support functions migrate in one particular area, there is a strong tendency for such migration to take place in other related areas.

4. Capability Transfer Through Subcontracting: The Experience of American Semiconductor Firms

When American semiconductor companies first moved assembly to offshore locations in Asia, assembly was a highly labor-intensive process. These companies maintained the skilled and capital-intensive design and wafer fabrication stages of production at a handful of locations in the U.S., and, a bit later, in Japan and Europe. Offshore chip assembly originally was thus initially the crudest form of "screw driver" assembly, with the result that training and local support requirements remained minimal. Nevertheless, even during this phase, some limited capability transfer did occur.

Take the case of Korea.[167] By opening up export channels for assembled chips and for simple consumer devices, both American and Japanese IC producers played an important catalytic role during the critical early phase of the development of the Korean electronics industry. One should also not underestimate the fact that this exposed Korean workers and managers to new organizational techniques, which, while not necessarily "best practice," certainly contributed to a gradual erosion of the traditional highly authoritarian Korean management practices and their inherent rigidities and inefficiencies. Cost-cutting and the need to comply with some minimum international quality standards also gave rise to some limited indirect learning effects related to the formation of production and investment capabilities. Yet, this was about all that foreign firms were willing to contribute during this early stage.

Starting in the late 1970's, this began to change. By then, American semiconductor firms had found out that it was next to impossible to resist the localization of certain activities. One factor was simply economic geography: the sheer distance from the U.S. to these offshore locations in Asia made it necessary to off-load some value chain functions locally in order to reduce the tremendous complexity of logistics. During the early 1980's, the appreciation of the U.S. dollar added further impetus to the willingness of U.S. firms to localize some elements of the value chain and to involve local subcontractors.

[167] For a detailed analysis of this process, see Ernst [1994a].

In response to such pressures, American semiconductor firms, notably Texas Instruments, Motorola, and Intel, began to transfer a certain amount of technological and organizational capabilities to their affiliates in Asia. Over time, some of these affiliates accumulated substantial knowledge in assembly and testing.

Take the case of Texas Instruments: "As far as assembly and testing are concerned we have more expertise here [i.e. in Malaysia] than we have in the U.S. We sometimes have to send our Malaysian engineers to the States to solve their problems."[168] In the case of Intel's Penang subsidiary, such expertise became particularly strong for the design and production of specialized automated assembly equipment. In 1983, when Intel set up highly automated assembly plants in Chandler/Arizona and in Ireland, the company had to rely on senior Malaysian engineers from its Penang affiliate for plant layout, equipment design, as well as for sorting out technical teething problems.[169] Intel Penang even claims that the first manager of its Mechanization and Automation group has been seconded to automate Intel's wafer fabrication lines in the U.S. and that its automation team makes substantial contributions to upgrade the level of automation in Intel's worldwide operations.

Over time, much of this knowledge has moved out of individual subsidiaries and has become widely diffused across East Asia. The irony is that chip assembly is no longer the uninspiring "back-end" of the semiconductor industry. Assembly and packaging technologies in this industry have become highly complex and play an important role for yields and performance features of leading-edge devices.[170] Much of the knowledge required for designing innovative new IC packaging technologies has migrated to companies in Korea (Anam Industrial, the world's largest IC contract assembler being a prime example), Taiwan, and Singapore. These countries are now among the leaders in IC packaging design.

This strengthening of local subsidiaries has also given rise to a number of domestic subcontracting arrangements which have facilitated the formation of specialized capabilities. Take again the case of Intel. In 1978, the company established a vendor development scheme, called "Executive Partnership Programme (EPP)," under which six local firms were selected to supply parts and automated equipment design, prototyping, and manufacturing services. For

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[168] Author's interview at Texas Instruments Malaysia, May 1984.
[169] This and the following information are based on an interview at Intel Penang, April 1992, jointly conducted by Ismail Salleh, deputy director of the Institute of International and Strategic Studies (IISS), Kuala Lumpur and the author.
[170] For detailed evidence, see Ernst [1991].

these companies, Intel guaranteed annual procurement volumes and provided process engineers and other support personnel to upgrade the skills of the supplier firms' engineers, designers, and machinists. In 1992, five subcontractors provided 80 percent of Intel's requirements for tool and die mold making and metal-stamping, three companies provided 80 percent of its plastic injection molding inputs, and two companies provided 85 percent of the required printed circuit board assemblies (Hakansson [1990], p. 260).

As a result of these arrangements, local subcontractors were able to reap substantial benefits, most importantly in terms of learning and capability formation. Some of Intel's original subcontractors have also started to build their own domestic supplier networks and thus have contributed to the development of domestic support industries. Lok Kim Teow Engineering (LKT) is a case in point.[171] When it was established in the 1950's, the company produced household fencing, window grills, and metal doors, in addition to minor maintenance and parts replacement for vehicles and ship engines. It was then a typical example of the many Chinese-owned metal working shops that existed in Penang.

Since 1978, participation in Intel's vendor development scheme has drastically changed the company and has led to a continuous upgrading of its technological and organizational capabilities. In 1991, out of total sales revenues of U.S. $6 million, automated equipment design and manufacturing (in particular precision tools for the semiconductor industry) accounted for 40 percent, parts fabrication, jigs and fixtures for another 40 percent, with the remaining 20 percent covered by mold design and manufacturing. In 1992, the company was beginning to reap the benefits of specialization and this product mix was expected to again change drastically. Automated equipment design has been farmed out to a sister company, Semiconductor Equipment Manufacturers (SEM), while LKT itself has put increasing emphasis on mould design and mould making, a market which since then has rapidly expanded. To implement this diversification strategy, LKT formed a joint venture with a Japanese mould designer who now works as an independent consultant in Malaysia. By choosing this partner, LKT was able to kill two birds with one stroke: it was able to tap into the long experience in mould making that specialized Japanese SMEs had developed over time and simultaneously gained contacts that would allow it to develop a market penetration strategy in Japan. Finally, LKT has also set up a

[171] Information on Lok Kim Teow Engineering (LKT) is based on an interview jointly conducted by Ismail Salleh, deputy director of the Institute of International and Strategic Studies (IISS), Kuala Lumpur and the author, May 1992.

satellite company to which it subcontracts parts fabrication and a variety of metal jobbing activities.

Underlying LKT's diversification strategy have been four basic motivations:

(1) A deeply entrenched inclination to avoid political risks in a hostile environment by pursuing an amoeba-like pattern of growth and splitting into ever new SME's.[172]
(2) To overcome its considerable problems in the recruitment of engineers and skilled workers (i.e. the demand for skilled labor in mould making was less acute than for precision tooling and automation).
(3) To rationalize the increasingly demanding intangible investment requirements related to R&D, product design, and marketing.
(4) And, probably of greatest importance, to reduce its excessive dependence on Intel's demand. In 1991, for instance, 80 percent of LKT's output was sold to Intel, with half of these sales being exports to Intel affiliates in the U.S., Singapore, and the Philippines (where Intel has another major assembly plant for integrated circuits).

Such diversification strategies in Malaysia have a good chance of success as local sourcing requirements have grown rapidly during the mid-1980's. This has been due primarily to the following developments:

- The upgrading of semiconductor assembly to include testing and technical support, as well as some front-end wafer fabrication and the increasing use of automated equipment, have generated a growing demand for a domestic precision engineering support industry.
- Of even greater importance has been the rapid spill-over of HDD assembly and component manufacturing from Singapore and the search for lower cost suppliers by drive manufacturers, as well as by the producers of key components, notably recording heads and disks. Again this has increased the demand for local precision engineering support.
- A huge inflow of Japanese FDI, particularly into consumer electronics, has substantially broadened the demand for local support industries. This is due to the fact that consumer electronics companies typically purchase a larger percentage of local inputs than semiconductor firms.
- The spread of international procurement offices (IPOs) in Singapore and the location of other regional headquarters functions related to logistics have led to some spill-over of demand to Malaysian sources.
- Substantial currency realignments in Malaysia have made inputs imported from Japan, Singapore, and Taiwan much more expensive and thus have induced firms from these countries to switch to local sourcing.
- Finally, and probably of greatest importance, has been the impact of regionalisation trends in the EU and North America which have encouraged intra-regional trade, sometimes at the cost of inter-regional trade.[173]

[172] While currently very little open discrimination exists against Chinese businessmen, the memory of earlier troubles is still fresh.
[173] For an early study of these effects, see Urata [1991], in particular, p. 44 passim.

This has led to the emergence of new regulatory barriers which constrain traditional procurement strategies and have forced firms to increase local content. For instance, the U.S. as well as the EU have started to impose much stricter requirements on ASEAN countries in terms of their Generalized System of Preferences (GSP) status. Certain minimum local content requirements need to be fulfilled so that exports of Japanese subsidiaries located in ASEAN countries can qualify for GSP status. This has forced Japanese firms to increase local sourcing.

A growth of local sourcing requirements does not automatically translate into growing demand for local suppliers. Alternatively, they can request their established suppliers back home follow suit and to set up shop in Malaysia. This can preempt, or at least slow down, the development of domestic support industries and the formation of local capabilities.[174] This can also constrain the formation of forward and backward linkages.

Take again Malaysia's electronics industry. In Malaysia, international subcontracting has led to the formation of three sets of industry clusters that have so far failed to interact: (1) the chip assembly cluster generated primarily by American companies; (2) the consumer electronics cluster generated by Japanese firms; and (3) a cluster performing satellite functions for Singapore's HDD and PC industries. The lack of forward linkages originating from the chip assembly cluster has been stressed time and again during my interviews in Malaysia: "All semiconductors... are exported--providing no forward linkages in the domestic economy. "This has led to " the ridiculous situation whereby a company based near a factory producing integrated circuits places an order with the manufacturer's parent company or regional marketing office. Components that were made in and shipped from Malaysia a few days earlier are then shipped back."[175] This is an important constraint, since timely and cost-effective access to key components, like semiconductors, is an essential prerequisite for developing a competitive electronics industry.

Over time, however, demand has also increased for domestic suppliers. There is now ample evidence to show that affiliates of foreign suppliers can, under certain conditions, play an important catalytic role in the diffusion of capabilities and can thus facilitate the development of domestic support industries.[176] As Japanese suppliers of components have set up shop in

[174] For evidence, see Lim and Pang [1991] and Rasiah [1995b].
[175] Author's interview at Ministry of Science, Technology, and Energy, Kuala Lumpur, Malaysia, October 1993.
[176] For evidence, see Mukoyama [1996], and Japan Association for Small Business Studies, 1994.

Malaysia (for consumer electronics and appliances) and Thailand (for the car industry), this has created a critical mass and appears to have facilitated the development of local suppliers.

Finally, existing subcontracting arrangements are facing new challenges. Local capabilities need to be continuously upgraded, a process which requires substantial investments. Local suppliers are also facing intensified competition. For standard parts, global sourcing from the cheapest location worldwide has become an established business practice. Moreover, any attempt to move up to higher value-added items is immediately confronted with increasing competition from foreign suppliers which will strive to set up local production facilities. Survival thus requires constant improvements: local suppliers have to increase their specialization, shift to longer-term cooperative relationships, participate early-on in joint product design and development, enter some of the existing buyer procurement information systems, and establish joint R&D projects with buyers (presumably by sharing some of the financial outlays involved).

A number of Asian governments now have fairly aggressive policies designed to facilitate such a continuous upgrading of local support industries.[177] While some local firms will not be able to cope with these new challenges, others will. The result that local capabilities will broaden and deepen. A striking example can be found in the rapid proliferation of wafer fabrication lines in East Asia that not only require huge investment thresholds (for DRAMs currently well above $1 billion), but also involve incredibly complex process technologies. For computer memories, Samsung, Lucky Goldstar, and Hyundai are now directly competing with the erstwhile Japanese market leaders, and firms located in Singapore and Taiwan have also established a credible position.[178] Over time, this will create further incentives for foreign electronics firms to broaden the scope of value chain activities that they move to Asian locations.

5. Capability Transfer by Japanese Electronics Firms

In what follows, I show how Japanese electronics firms have gradually broadened the scope of the value chain activities they are moving to East Asia. I have chosen to focus on this example for the simple reason that most people believe that, of all possible candidates, Japanese firms would be the last to proceed with such an opening-up of their international production networks. It is still widely believed that Japanese electronics firms in Asia rely on closed and

[177] For a good overview, see Takeuchi [1993], p. 52-54.
[178] For an analysis of the strengths and weaknesses of Korean semiconductor firms, see Ernst [1994].

shallow production networks that are in essence restricted to basic assembly activities. Nothing could be further from the truth.

Since the beginning of the 1990's, Japanese electronics firms have shifted an increasing number of stages of the value chain to East Asia.[179] Two aspects are of particular importance: (1) changes in the procurement system; and (2) at least partial redeployment of some R&D functions.

5.1. Procurement

Fundamental changes are currently emerging in the East Asian procurement patterns of Japanese electronics companies. With the Yen-appreciation as a major catalyst, the overriding objective is to reduce the dependence of Asian production subsidiaries on high-cost input imports from Japan. The challenge is how to achieve these cost savings without losing too much in terms of quality, speed, and reliability of delivery.

Take the case of Hitachi, a behemoth whose consolidated sales equal roughly 2 percent of Japan's gross national production.[180] Earlier than many of its Japanese rivals, Hitachi internationalized procurement and continues to upgrade these activities in response to changing competitive requirements. In the early 1970's, Hitachi was among the first Japanese electronics firms to set up overseas procurement bases in the U.S. and Hong Kong. In 1979, a European procurement base was added in Germany. Following the Plaza agreement in 1985, Hitachi established an International Procurement Department which was separate from its Materials Department, which had traditionally handled all purchasing activities. The original motivation was to soften trade friction with the U.S. by increasing the share of foreign imports. This focus on arms-length imports is reflected in the fact that one of the first activities of this new department was to send import missions to the U.S., China, and Korea whose main purpose was to identify and check the quality of parts that Hitachi could import.

Since 1989, Hitachi has made a consistent effort to upgrade its international procurement functions. Rather than relying on arms-length imports from independent foreign suppliers, the focus has shifted to reverse imports from foreign affiliates and to OEM imports from technical tie-ups with foreign companies, for instance Goldstar in Korea. At the same time, Hitachi

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[179] The following is based on Ernst [1997b].
[180] The following is based on interviews with Hitachi, November 1993.

established a number of new International Procurement Offices (IPOs) in San Francisco, Singapore, Seoul, and Taipei. It also began to provide assistance to cut prime costs and to train foreign suppliers.

For quite some time, however, Hitachi's attempts to deepen its international procurement functions remained fairly limited. It was only after the Hitachi group announced a major reorganization in August 1993 that this process of deepening got under way in a serious manner. In the same month, Hitachi established a Center for the Promotion of Procurement in Asia in Singapore. While Hitachi's IPOs, for all practical purposes, have been commercial purchasing offices staffed primarily by buying agents, the new Center involves engineers from both Hitachi and its suppliers in all stages of the procurement decision, including component design and materials specification. The Center thus acts as a mechanism for bringing foreign suppliers into Hitachi's internal design processes and for shifting to longer-term supply arrangements. The Center is also supposed to provide training for local/regional materials experts and to coordinate Hitachi's procurement plans with the sales efforts of different host governments.

One important aspect relates to the role of policy incentives provided by both the Japanese government and by various host countries in the region that have induced Hitachi to rely more on procurement in Asia. In short, tax incentives for import promotion developed by the Japanese government have helped Hitachi to reduce the cost of importing components from East Asia. The irony is that these incentives were originally developed in response to pressures from various U.S. administrations which were meant to increase the domestic market share for U.S. companies, while in reality they have facilitated some overdue organizational adaptations of Japanese firms.

At the same time, host country policies have also been of great importance. In Malaysia, for example, Hitachi, Matsushita, and other Japanese firms have closely cooperated with the government's programs for promoting domestic industries. One example is the Penang Skill Development Center of the Penang Free Export Zone, where Hitachi and Japanese parts manufacturers participate in training programs for local parts manufacturers.

Important changes have also occurred in the role of Japanese component suppliers. Those firms that produce relatively complex and high value-added components have substantially increased their investment in East Asia, primarily in Malaysia and Thailand, but also increasingly in China. Once production has been established in East Asia, these suppliers are much less inclined to stick to their traditional clients. Indeed, in order to amortize their substantial investment outlays and gain economies of scale as quickly as possible, these affiliates are now actively searching for new clients. The result is that they frequently supply a number of Japanese companies as well as American, Korean, and some European firms.

The higher-level Japanese components suppliers that have set up shop in East Asia are now under increasing pressure to involve local supplier firms for lower-end subcontracting and contract manufacturing activities. This is due to the fact that many small Japanese suppliers of low-end, general purpose components have either been forced to close down production or cannot raise the funds required for overseas production.

Finally, a third important consequence of the Yen appreciation is that Japanese affiliates in Asia have begun to increase their purchases from both Taiwanese and Korean suppliers. One of the most prominent changes in the Japanese regional production networks is that, especially for computer-related products, Japanese firms are now relying much more on OEM and joint production arrangements with Taiwanese and Korean firms.

Since 1994, Japanese PC manufacturers have drastically increased their purchases of PCs, motherboards, terminals and monitors, and a variety of other PC-related products from Taiwanese computer companies. NEC, for example, gets monitors and motherboards from Tatung and Elite, while Fujitsu, Epson, Canon, Hitachi, Sharp, and Mitsubishi have all become major OEM customers.

There is no doubt that Japanese PC vendors perceive this increase in OEM purchases as an intermediate solution: it enables them to quickly discontinue lower value-added production activities at home while at the same time enabling them to gain time until they set up their own supply base for some of these products in China and Southeast Asia. This implies that the rapid growth of OEM contracts is unlikely to last. This is especially true as some Japanese PC makers have now started to move some production in-house, taking it away from Intel and Taiwan contract manufacturers.[181]

For instance, Fujitsu, Hitachi, and Toshiba are ramping up PC output in their own Japanese plants and thus cutting back or eliminating their re-labeled OEM purchases from offshore contract companies. Prior to the current move back to production in Japan, both Fujitsu

[181] EBN Online, 7-1-96, "Japanese PC Makers Move Production In-House."

and Hitachi were using Acer Inc. of Taiwan to make PCs sold in Japan under their own labels. The move back to Japan is obviously a response to the gradual depreciation of the Yen which started in 1995. Indeed, there is a perception that it is now again possible to use ICs and components from their domestic sister divisions.

This example indicates that nothing is automatic about the shift to systemic globalization and that, periodically, it may face important reversals. The question is how long Japanese PC producers will be able to reverse the trend toward outsourcing in East Asia. A relocation of PC assembly back home obviously has considerable short-term benefits for the component divisions of integrated Japanese electronics firms. But whether this can provide a long-term solution remains open to doubt. For instance, it is unlikely to facilitate the expansion of international market share. After all, one of the great advantages of Taiwanese OEM suppliers has been the incredible speed with which they are able to respond to changes in markets and technology. Japanese vertically integrated electronics giants are not famous for such flexibility.

5.2. Transferring Some Elements of R&D

Japanese electronics firms are now experimenting with new approaches to innovation management. This has far-reaching implications for the organization of their Asian production networks. Most importantly, it may help to improve the capacity of Japanese firms to mobilize and harness the region's capabilities.

These experiments are driven by the need to outsource a variety of capabilities that either have become too expensive in Japan or that only very few firms can afford to retain. This reflects the efforts of Japanese electronics firms to emulate the successful strategies of American electronics firms; in short, Japanese firms have increased their specialization and strengthened their core competencies through greater reliance on outsourcing.

There is a rich literature on the comparative strengths of innovation management by Japanese firms. This literature stresses the capacity of Japanese firms to reduce the development cycle for new products and thus to accelerate speed-to-market, as long as these products remain within a given technology paradigm.[182] A continuous refinement of product design and process engineering have been hallmarks of the Japanese approach to innovation management.

[182] Important contributions include Mowery and Rosenberg [1990], Kenney and Florida [1993], Nonaka and Takeuchi [1995], and Branscomb and Kodama [1993].

However, more recent research, conducted mostly by Japanese researchers and not well known in the West, has highlighted some important weaknesses of the international innovation management strategies of Japanese electronics firms.[183] This research suggests that, compared to their American and European counterparts, Japanese firms are still at a relatively early stage of R&D internationalization and have very limited experience in organizing international R&D networks.

One of the pioneers of such outsourcing strategies for innovation has been Canon, the highly successful computer printer, copier, and camera company.[184] Over the past decade, this company has devolved significantly more management control to foreign subsidiaries, hired a greater proportion of foreign staff and management, and absorbed more ideas from abroad than is the Japanese norm. The first step in this direction took place in 1990 when Canon set up five overseas R&D centers, which now employ 15 percent of its R&D staff. In 1996, Canon gave its U.S. research unit global responsibility for software, established a French global telecommunications research unit, and an automated language translation center in the United Kingdom. Today, half of Canon's global workforce works abroad, up from 30 percent a decade ago. Of the 40,000 outside Japan, only 900 are Japanese.

The main driving force for relocating R&D activities to East Asia is the current shift from proprietary components to standard components that can be sourced at lower cost from local or regional suppliers. In order to achieve this goal, Japanese electronics firms are all forced to upgrade their regional and local support services.

A second important incentive for Japanese electronics firms to expand their R&D activities in Asia is to tap into existing pools of lower-cost human resources. Most countries of the region pursue quite aggressive policies to increase the supply of engineers and scientists; software engineering, certain basic assembly technologies, some areas of circuit design, and certain areas of system engineering and integration are of particular importance. Japanese electronics firms are under tremendous pressure "...to reconstruct their advantages

[183] The following account is based on Abe [1992], and interviews in the Japanese electronics industry, November 1993, and June 1995.
[184] William Dawkins, "Time to pull back the screen. Japanese multinationals may follow Canons example and shift power overseas", *Financial Times*, November 18, 1996.

internationally...[through] internalization of human resources of host countries within each company group."[185]

As a result of the closed production networks which they had established during the 1980's, Japanese companies now face much greater difficulties in recruiting top local engineers, especially compared to American companies. After some unsuccessful attempts to headhunt engineers by paying higher salaries, Japanese firms have now developed a peculiar recruitment approach that builds on some inherent strengths of the Japanese production system.[186] Thus, they now hire most of these local engineers internally. Based on a careful selection process, each affiliate develops a pool of highly motivated "technicians" who are then trained over a period of 5 to 7 years to become (possibly unlicensed) engineers. This accounts for the relatively low turnover at the engineering level (i.e. the new engineering skills are firm-specific). This peculiar recruitment approach obviously builds on existing strengths of the domestic Japanese production system. At the same time, it allows the Japanese firms to overcome two problems: (1) most host countries limit the immigration of Japanese engineers, and (2) there is an implicit understanding among Japanese firms that bidding up salaries to attract engineers should be avoided.

The third important incentive for Japanese electronics firms to expand their R&D activities in Asia is that Japanese firms now attach much greater importance to market intelligence and product customization. They are increasingly conscious of the fact that Asia is characterized by very heterogeneous demand patterns and highly segmented product markets. At the same time, the variety of production sites has kept increasing, with the result that Japanese firms now have to adapt their Asian production networks to the idiosyncrasies of each of these markets. As a result, local affiliates need to have a capacity for continuous product customization and Japanese companies have been forced to establish on the spot a capacity for continuous re-design (adaptive engineering). Adaptive engineering and some development activities have thus become increasingly decentralized and now take place in engineering departments of Asian manufacturing affiliates.

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[185] Tejima [1996], reporting on the most recent annual questionnaire survey of the Export-Import Bank of Japan.

[186] Most of my interview partners in Japanese electronics firms emphasize that they cannot merely replicate the U.S. model of international production. This supports my argument that changes in the organization are path-dependent, in the sense that they are shaped by peculiar features of the domestic production system. For Japanese firms, this implies that they have to come up with an organizational response that is based on and amplifies the strengths of their domestic production system. One prominent example is the distinctively different approach of Japanese electronics firms to human capital formation in Asia.

Table 2 summarizes some empirical evidence for R&D activities of Japanese electronics firms in East Asia. I distinguish five categories:

Table 1: Japanese Electronics R&D Activities in East Asia

	CHINA					HONG KONG					KOREA					MALAYSIA					SINGAPORE					TAIWAN					THAILAND				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
AIWA																								x											
ALPINE			x																																
CANON													x													x									
CASIO																			x																
FUJITSU			x					x														x	x				x								
HITACHI			x														x		x							x									
JVC																					x														
MATSUSHITA																x			x			x	x		x		x	x	x						
MELCO																x																			
MITSUB.CORP			x																																
NEC			x					x	x														x				x						x		
NESIC																															x				
SHARP														x					x								x	x							
SONY																			x				x			x									
TDK																			x																
TOSHIBA							x					x										x		x			x								
UNIDEN						x																													
TOTALS:			5			1	1	2	1			1	1	1		2	1		6		1	3	4	2	1	3	5	2	1		1		1		
COUNTRY TOTALS:	5					5					3					9					11					11					2				

LEGEND:

I - ADAPTIVE ENGINEERING (8 total)

II - IC DESIGN (11 total)

III - SOFTWARE ENGINEERING (15 total)

IV - PRODUCT DEVELOPMENT (11 total)

V - GENERIC TECHNOLOGY DEVELOPMENT (1 total)

GRAND TOTAL: 45

Source: BRIE FDI Database, based on news reports.

(I) Adaptive engineering, i.e. engineering activities that go beyond basic manufacturing support services and include the incremental adaptation and improvement of products and processes.[187]
(II) Circuit design.
(III) Software engineering (ranging from simple program reconversion to fairly sophisticated projects).
(IV) Product development, most of it for the local market, and a few projects for the regional market.
(V) Generic technology development, i.e. major innovations with a huge potential for productivity enhancement and the creation of new product markets.

[187] Basic manufacturing support services are defined to include activities like calibration and testing, die and tool services, (preventive) maintenance and repair, and quality control.

The table shows that out of a total of 45 projects, only one falls under the category V. This project, the Matsushita audiovisual information research center in Singapore, was established in 1990 and focuses on the development of compression technology for image transmission required for videophones and multimedia. Eleven projects are reported to involve product development. Yet, category IV is quite problematic as we cannot distinguish to what degree it might actually consist of simple tasks involved in category I. To avoid double-counting, where category IV activities take place, category I has not been marked (unless these simpler activities occur for a different product line than the category IV activity). The result is that our classification probably underestimates to what degree Japanese electronics firms in East Asia still concentrate on relatively simple adaptive engineering activities (category I).

The largest share of Japanese electronics R&D activities in East Asia falls under two categories: software engineering (15 cases) and circuit design (11 cases). The essential point to stress is that in most cases both are essentially support services required to enter or expand the region's domestic markets. For software engineering, for instance, the development of Chinese language programs plays an important role, with the objective to improve the market position in China for Japanese computer manufacturers. And most of the circuit design activities are dedicated to ASICs (application-specific integrated circuits) that are required for consumer devices or telecommunications equipment sold in the domestic or regional markets. Both Singapore and Hong Kong have recently emerged as regional IC design centers for consumer devices. Japanese firms are now concentrating their limited resources at home on higher value-added products related to computing, multi-media, and networking applications, and are thus eager to redeploy design and engineering functions for audiovisual equipment and home appliances. Take the example of Sharp's IC design center in Singapore, which currently consists of ten people.[188] Apart from after-sales support services, its main function is the programming of microcontrollers embedded in home appliances. Over the next years, Sharp intends to use this center in order to outsource design work from Japan on a much larger scale; by 1998, the company plans to increase the center's staff to 30 people.

[188] Based on author's interviews at Sharp headquarters, June 1995.

6. Outsourcing in the Computer Industry

6.1. The Increasing Importance of Outsourcing

Over the last decade, outsourcing has become an important practice in the electronics industry. This is especially true as firms focus more closely on core activities and competencies and purchase various intermediate goods and services from other firms. American computer companies, notably Apple, Compaq, and HP, have been pioneers in the subcontracting of component manufacturing as well as in contract assembly. Likewise, the spread of OEM and, more recently, ODM arrangements enable these firms to concentrate on what they do best. Today, it is normal that the supply chain of a computer company spans different time zones and continents. For instance, final assembly is usually dispersed to major growth markets in the U.S, Europe, and Asia, microprocessors are sourced from the U.S., memory devices from Japan and Korea, motherboards from Taiwan, HDDs from Singapore, monitors from Korea, Taiwan, and Japan, and keyboards and power switch supplies from China.

The picture gets blurred, however, as many of these suppliers in turn ship their products from widely dispersed overseas affiliates. The complexity of the logistics involved is truly mind-boggling.

For a typical PC company, the costs of components, software, and services purchased from outside has increased from less than 60 percent in the mid-1980's to more than 80 percent of total (ex factory) production costs today.[189] As external sourcing relations become increasingly complex and often involve locations on different continents, they are fraught with very high coordination costs. Some firms report that the share of coordination costs in overall production costs is nearly as high as that of the costs of in-house manufacturing activities.[190] In other words, the cost of coordinating such outside relations may now exceed the cost of internal value generation and have become a crucial concern for strategic management. As a result, the focus of cost reduction strategies is shifting from scale economies in manufacturing to a reduction of the cost of external sourcing.

It is important to emphasize that outsourcing is no longer confined to parts and components but involves as well a variety of high-value added support services, including

[189] These and the following figures are based on company interviews, as reported in Ernst and O'Connor [1992], p. 34, 37.

[190] Such costs are typically defined as "... all incremental cost associated with dealing with suppliers remote from the initial design site and/or the final assembly site," with communication costs and administrative overheads absorbing the largest share. See Ernst and O'Connor [1992], p. 34, 37.

product customization, product design, and production technology. A typical example is the spread of "turnkey production arrangements" in the PC industry. Compaq, in a recent contract with Taiwan's Mitac International, has out-sourced all stages of the value chain except marketing, for which it retains sole responsibility.[191] Mitac is responsible for the design and development of new products, as well as for manufacturing, transport, and after-sales services at its manufacturing facilities in Taiwan, China, the United Kingdom, Australia, and the U.S. Mitac's greatest attraction for Compaq are its plants and sales subsidiaries that are located in most of the world's key computer markets. Ultimately, Compaq expects to save up to 15 percent in overall life-cycle costs.

6.2. Motivations for Outsourcing

What factors have induced these companies to increase their reliance on outsourcing? During the early 1980's, the appreciation of the U.S. dollar and the resultant increase in the cost of capital have played an important catalytic role. In short, outsourcing was seen as an effective instrument for accelerating the turnover of capital.

A second important concern relates to the potentially huge economies of scale that can result from a combined strategy of rationalizing and internationalizing a firm's supplier networks. Rationalization means consolidating sources of materials and components and paring down a company's supply base. Internationalization means that a firm can choose the best suppliers in the world, in terms of cost, quality and delivery performance, no matter where their operations are located. Together, rationalization and internationalization mean that the average size of each contract is likely to increase. As a result, the client firm can request that each supplier offers more favorable unit prices and delivery schedules. If the contract is big enough, the client firm may even be able to ask the supplier to set up shop at a particular location.

Reaping the potentially huge scale economies of international procurement, however, requires that the firm implements important changes in the organization of the procurement function. For low-volume, low-cost commodities (especially those with high transportation costs), procurement decisions can be decentralized (i.e. left to regional headquarters or even to individual affiliates). For high-volume, high value-added components, on the other hand, procurement needs to be centralized. Important changes also need to be made within the firm. In

[191] Information provided by MIC/III, October 27, 1995.

order to be able to reap the benefits of international procurement, decisions need to be based on close and continuous interaction between purchasing, engineering, finance, and quality assurance. This is an example of how the effective implementation of inter-firm networks depends upon progress in intra-firm networking.

Outsourcing is also motivated by a strategic concern: in order to survive the extremely intense competition that is characteristic for the electronics industry, global competitors are forced to concentrate on product development (architectural design) while at the same time remaining a low-cost producer. In order to meet these goals, firms tend to focus on R&D, the production of some key components, and some limited involvement in the highly automated final assembly of higher value-added products. By outsourcing most of the other activities, these firms expect to reduce the high fixed capital cost burden and risks that would result from any expansion of in-house production facilities. In addition, outsourcing is also expected to improve a firm's capacity to flexibly adjust output to excessive demand fluctuations.

In response to these pressures, a number of U.S. HDD manufacturers have increasingly relied on external sources for components and subassemblies. In 1992, for instance, both Maxtor and Conner Peripherals sold their component factories in Penang to Read-Rite, a specialized American component supplier. In 1984, Quantum established a close relationship with Matsushita Kotobuki (MKE), a majority-owned subsidiary (57.3 percent) of Matsushita Electric Industries Company of Japan.[192] Quantum's management assumed that nothing could stop Japanese firms from taking the lead in the HDD industry, as they had done before for floppy disk drives (FDDs). Thus, linking up with a Japanese partner was conceived as an effective insurance policy that would shield Quantum from aggressive attacks. Quantum also expected that this cooperation would lead to substantial economies of specialization: Quantum would supply design and marketing expertise, while MKE would supply the manufacturing know-how.

Quantum chose MKE for four reasons: (1) MKE was a pure manufacturing company which had always depended on the designs, marketing, and sales efforts of the parent company for the products it manufactured. Thus, Quantum concluded that MKE was unlikely to become a direct competitor any time soon.[193] (2) MKE had an excellent reputation as a leading-edge

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[192] Form 10-K Quantum Corp., Fiscal Year Ending March 31, 1995.
[193] In the light of recent developments, this assumption becomes now highly debatable. While originally MKE supplied only low-end drives, it now produces Quantum's full product range, including the highly profitable high-

producer of electro-mechanical components and systems that required precision engineering. Its VCR manufacturing lines were among the most highly automated and efficient, and the company was famous for its capacity to quickly ramp up production and improve yields once a decision had been made to start production. (3) MKE was willing to provide substantial funds and human resources, clearly indicating a long-term commitment. And (4) MKE went out of its way to commit itself to continuous cost improvements. In particular, MKE was willing to accept a pricing arrangement incorporating risk-sharing in the event of exchange rate fluctuations.

6.3. Implications for Local Capabilities: The Example of OEM Arrangements

OEM arrangements differ from subcontracting arrangements in that they involve the production of final products. OEM arrangements are probably one of the least costly ways for a firm to enter international markets. In such arrangements the customer provides detailed technical "blueprints" to allow the contractor to produce according to specifications. Often, technical assistance in engineering and process technology is also provided, in order to ensure quality and cost efficiency.

Because the customer is also responsible for marketing and distribution, in addition to the procurement of key components and R&D, the OEM supplier can avoid the huge investment outlays required for these activities and thus can concentrate on the development of its core capabilities. In order to qualify as an OEM supplier, a firm must already have developed considerable technological capabilities and organizational competence, particularly for production, investment and adaptive engineering. These capabilities need to be continuously upgraded in order to avoid losing OEM status. Such upgrading is particularly important if the firm seeks to move up to the higher value-added segment of the OEM market. This is true, in particular, if the supplier wants to be upgraded to ODM (original design manufacturer) status where, in addition to manufacturing services, it provides a detailed product design based on the fairly loosely defined requirements of the customer. Obviously, the capacity to improve upon existing designs and to further develop them constitutes an important upgrading in the development of technological capabilities.

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end drives for mainframes and network servers. One wonders how long MKE will wait till it disconnects itself from Quantum and enters the market on its own.

7. The Joint Migration of Key Support Functions

7.1. Systemic Rationalization

As the scope of international production expands and increases complexity, cross-functional linkages increasingly cut across national borders. This implies that rationalization must follow suit and cover a variety of cross-border linkages. This has important implications for decisions on where to locate which stages of the value chain. Systemic rationalization implies that a firm will attempt to locate functions to facilitate closer, faster, and more cost-effective interaction between different business functions across different locations.

Rationalization also cannot end at the boundaries of the firm, but must be extended to include the linkages with suppliers and distributors. Given the extreme complexity of logistics that characterizes the HDD industry, rationalizing supplier linkages has received a high priority.[194] A rationalization of distributor linkages is likely to be the main priority for computer companies: they produce a broad mix of complex products and sell them in many different markets, with the result that they constantly need to deal with a variety of complex coordination problems related to demand management.

Electronics firm may thus differ in the original focus of such rationalization exercises. What matters for our purposes is that, once rationalization has been started in one particular area, it has an inherent tendency to broaden and to move on to other activities as firms constantly try to improve their interactions.

7.2. The Example of Hewlett Packard

Take the example of Hewlett Packard (HP) and its approach to the rationalization of its worldwide distribution channels.[195] HP produces products and services where time-to-market and efficient order fulfillment are decisive for competitive success. Inventory management was a serious weakness of HP during the late 1980's. It accumulated inventories worth billions of dollars and customers were highly critical of the speed and reliability of order fulfillment. Profit margins were seriously affected and there was a real threat to HP's competitive position.

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[194] One of the objectives of the Sloan Foundation project on the globalization of the HDD industry is to trace such changes in the industry's global supply chain.
[195] The following discussion is based on Lee and Billington [1995], Dataquest [1993], and BRIE's Database on International Production Networks.

In order to improve order fulfillment, HP initially focused on a rationalization of inventory management. But it soon became clear that the net had to be cast much wider, and that control over its distribution channels needed to be tightened. HP usually does not own these channels. For all practical purposes, however, they are an integral part of HP's international production network. Thus, in 1991, HP began to extend a division's supply chain to include the inventory systems of a number of major dealers. The immediate goal was to reduce unnecessary duplication of safety stocks.

Once started, however, such partial rationalization had an inherent tendency to branch out into other activities. As HP was able now to control its distributors, they could also be asked to perform additional functions. The result is that distribution agents today also have to shoulder responsibility for a variety of other activities, including parts procurement, power supply modules, performing final product differentiation and customization, and ensuring quality--all functions that had not previously been part of their normal routine.

HP now needed an organizational innovation to enable it to control such complex linkages and improve their interactions. The company began to implement a concept called "delayed product differentiation, "which has been critical to the company's successful reorganization. This concept goes well beyond the traditional concept of "design for manufacturability"(DFM).[196] In HP's view, the DFM concept has failed to cope with crucial problems related to international logistics and distribution. It did not improve the firm's capacity to respond to unexpected changes in customer demand and also failed to reduce a number of hidden costs which resulted from the expansion of international production.

HP chose a different approach: it delays product differentiation and customization as long as possible until the product has already moved quite close to the customer. By 1993, HP was fully committed to this approach (the so-called "design-for-localization" concept). It now designs all its new products so that they can be customized at individual distribution centers. Delaying product differentiation is expected to improve HP's capacity to respond to unexpected demand fluctuations at short notice and with a minimum of extra cost. "By delaying product differentiation one delays as much as possible that moment when different product versions assume their unique identities, thereby gaining the greatest possible flexibility to changing

[196] Firms differ in their precise definition of DFM guidelines. These definitions also differ across products and time. See Levy [1994], p. 343.

customer demands. Flexibility can improve the cost-effectiveness of the supply chain, because inventories are stocked in the pre-differentiation form." (Lee and Billington [1995], p.55.)

In practice, this means that customization, as well as important aspects of product differentiation, are moved out of factories and are performed by individual distribution centers close to customers. As HP has distributors around the world, this implies a migration of customization functions abroad.

This has important implications. It implies that the boundaries between manufacturing and distribution are becoming blurred. This suggests that the analysis needs to move beyond only the location of manufacturing facilities and supply sources to include the allocation of distribution and service activities. It also implies that the distinction and the division of labor between the home location and select foreign locations may become increasingly fuzzy over time. Functions that used to be the sole privilege of the home location (or a few locations within the home country), must now be performed as close as possible to the final customer. This could lead to important qualitative changes in the organization of international production. Over time, the accumulation of product differentiation capabilities in a number of overseas distribution centers may reach a critical threshold. Sooner or later, some of these locations may also perform product design functions.

7.3. The Role of Proximity: New Options for Co-Location Abroad

We are now coming back to a question that we raised at the beginning of chapter II: why is it that firms have moved to international production, despite the advantages of proximity that a consolidated location at home can provide? Does proximity matter and how has it shaped the organization of international production?

In what follows, I argue that the link between close cooperation and co-location may be somewhat looser than is normally assumed in the literature. There may thus be alternative and more indirect ways to achieve close cooperation that do not necessarily require physical co-location. Of even greater importance is that some forms of proximity may be less constraining than others to a redeployment of production overseas. Indeed, it may actually be possible to reproduce these particular proximity effects at some of the foreign locations. In this sense, one could argue that proximity has actually played an important role in the shift from partial to systemic forms of globalization.

Proximity can mean a variety of things, depending on which stages of the value chain are involved. Five different types of proximity requirements can be distinguished: (1) proximity to engineering support; (2) proximity to suppliers; (3) proximity between prototyping and volume manufacturing; (4) proximity to lead users;[197] and (5) proximity between process and product development.

It can be argued that each of these different proximity requirements has different effects on the scope for international production. Some, for instance, proximity to engineering support and to suppliers, can be reproduced abroad, but this may be much more difficult for others.

(1) Proximity to engineering support

The first type of proximity concerns the distance between manufacturing sites and engineering support activities, such as preventive maintenance, the adaptation of jigs and fixtures, recalibration, and testing. This type of proximity is crucial for a firm's capacity to quickly ramp up and ramp down the relevant production lines as well as for a quick progression along the learning curve. Engineering support activities tend to follow the redeployment of production at a relatively early stage, i.e., once production moves beyond screwdriver assembly. Historically, testing has been the most resistant to overseas redeployment, due to the very high cost of testing equipment and the complex procedures required for sophisticated testing methods. In the semiconductor industry, for example, testing was concentrated in Singapore and remained separated for quite some time from the final chip assembly locations in East Asia. Such constraints are now much less severe as test equipment and software have become more rugged and user-friendly. Today, most of these engineering support services are available in East Asia, and some of them at a distinctively lower marginal cost than in the U.S. This type of proximity thus does not unduly constrain relocation.

(2) Proximity to suppliers

Proximity to suppliers affects the cost and complexity of logistics. But it also affects speed-to-market, delivery times, and the scope for just-in-time inventory management. Distance from suppliers can magnify the impact of unexpected disruptions, notably by late delivery or by the delivery of defective materials. Such disruptions can have devastating effects, especially in

[197] Von Hippel defines "lead users of a novel or enhanced product, process or service as those that "... face needs that will be general in a marketplace, but... (who) face them months or years before the bulk of that marketplace encounters them... (and who will)...benefit significantly by obtaining a solution to those needs." See von Hippel [1988], p. 107.

those sectors of the electronics industry where product cycles have been ruthlessly cut, where the speed of response to changing technologies and markets is critical, and where production requires a great variety of components and sub-assemblies. This is especially true if the components and subassemblies have very demanding design features and tolerance requirements. After what we learned in chapter I about some of the specific features of the HDD industry, it is plausible to assume that proximity to suppliers is a major concern.

This raises an important question: where are the suppliers for the HDD industry located? We know that for recording heads, there is only one stage of production which has not been geographically dispersed, i.e. wafer fabrication. For all other stages of the manufacturing process, in particular HGA and HSA, we find a variety of approaches to geographic location, although most of these sites now having moved to Asia. The picture is different for media production, which has experienced very limited geographic dispersion. Outside the triad, there are only Conner and StorMedia in Singapore, Komag in Malaysia, and Conner in Mexico. Interestingly, Seagate Magnetics is consolidated in California.

Yet, what matters for our purposes is that there is evidence to argue that co-location can occur anywhere, and that this applies for both front-end and back-end processes.[198] For instance, Komag co-locates front-end processes both in Japan (at its KMT joint venture subsidiary) and in Sarawak/Malaysia. StorMedia has co-located front-end activities in Singapore while it performs back-end activities in both Santa Clara/CA, and Singapore. The focus, however, appears to be shifting to Singapore.

The next step then is to ask where the suppliers of the suppliers are located. For instance, where are the lower-tier suppliers located that produce intermediate inputs to the head and media producers? Media companies typically rely on external suppliers, in many cases a sole supplier, for certain materials used in their manufacturing processes. These materials include aluminum substrate blanks, finished substrates (in some cases glass/ceramic substrates), nickel plating solutions (if it makes its own finished substrates), lube and buffing tapes, slurries, certifier heads, sputtering target materials, and certain polishing and texturing supplies. Media companies also purchase sputtering, texturizer, lubricator, glide tester and certifier equipment from suppliers, as well as plating and polishing services.

[198] The following draws on David McKendrick, Profile of Suppliers of the HDD Industry: Media and Heads, June 21, 1996.

There is some evidence that media companies need to work closely with a limited number of suppliers in order to ensure a reliable source of supply. Changing suppliers for certain materials--such as the lube or buffing tape--would require that the products be re-qualified with each customer. Re-qualification could prevent early design-in wins or could prevent or delay continued participation in disk drive programs into which a company's products have been qualified. With few exceptions, however, we do not know who supplies these materials, equipment, and services nor what proportion of the cost of a finished disk they represent.

The same is true for suppliers to head companies that produce certain key materials such as wafer substrates, photoresist, suspensions, and certain types of production equipment. Other than Hitachi Metals, which provides MIG sliders to Read-Rite, and Hutchinson, the world's largest manufacturer of suspensions, we do not yet know much about these suppliers.

Overall, however, there is sufficient anecdotal evidence to indicate that, in principle, there are no major constraints to a progressive geographic dispersion of a variety of such supply sources and that some suppliers are now located in East Asia. This type of proximity is thus likely to facilitate rather than constrain a relocation of HDD assembly to the region. The scope for such relocation has substantially increased in a relatively short period of time.

(3) Proximity between prototyping and volume manufacturing

A third type of proximity concerns the spatial distance between prototyping and volume manufacturing. This type of proximity is often essential for a quick solution to the teething problems that accompany the ramping-up of any new production facility. It also facilitates design modifications at an early stage in the product cycle. In the HDD industry, prototyping is almost exclusively restricted to a few regions in the U.S. This causes tremendous problems for attempts to speed up the transfer from prototyping to the high-yield volume production sites in Asia. One possible response to this type of proximity problem is to relocate some volume production back to the U.S. But is this the only option? We know that Singapore has developed an excellent infrastructure for a variety of value chain activities that, in a few cases, now also include product design. Likewise, given the advances in computer-based design automation and in exchanging design data over computer networks, there are now fewer constraints to a redeployment of prototyping. Advances in CAD and CAE, however, may have also reduced the necessity for co-location.

In addition, we know that all firms in the computer and disk drive industry are under tremendous cost reduction pressures and that some locations in Asia have developed pools of lower-cost design engineers. Wouldn't this imply that sooner or later, it makes sense to move prototyping to where mass production is? And then, from there, where will this lead to?

(4) Proximity to customers

Proximity to customers may often be necessary to collect feedback early on customer requirements. This type of proximity appears to be of particular importance in the HDD industry. As suppliers of an intermediate input to the computer industry, HDD firms compete for design-ins by computer companies. As a result, computer companies exert a lot of influence on the product mix, the product cycle and the pricing strategies of HDD manufacturers. HDD firms thus have to solicit a set of detailed product specifications from potential customers during the early phase of the development of a new computer generation. Traditionally, American computer companies have kept design in a few locations in the U.S.

In turn, this has created a powerful incentive for HDD producers to keep design in the U.S. Without exception, all research and product design activities remain concentrated in the U.S. or Japan. There is no indication that, in the near future, these firms will consider moving R&D to locations in East Asia. The same is true for the location of R&D for heads and media which are, almost without exception, carried out in the U.S. (mainly California) and Japan.[199] The exceptions are marginal players from Korea and Taiwan, which now engage in R&D.

We also find, however, that the link between close cooperation and co-location may be somewhat looser than is normally assumed in the literature. Put another way, there may well be alternative and more indirect ways to achieve close cooperation that do not necessarily require physical co-location. Take, for instance, collaboration in the design phase between the suppliers of recording heads (a key component) and the final drive assemblers.[200] Such collaboration needs to be very intense. Apparently, however, it can be well handled if the head makers send their designers for a limited period of time to the premises/research labs of the HDD firm. Thus, the two design shops do not need to be proximate.

But there are also signs that more drastic changes could happen in the future. Take the example of computer design. Design in this context means the capacity to make quick changes in

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[199] David McKendrick, Profile of Suppliers of the HDD Industry: Media and Heads, June 21, 1996.
[200] Based on David McKendrick, Profile of Suppliers of the HDD Industry: Media and Heads, June 21, 1996.

the configuration of motherboards in order to be able to integrate the latest microprocessor generation. While this is a very demanding requirement, one should not lose sight of the fact that this is something quite different from the capacity of a firm to define architectural standards and thus create new markets.

Over the last few years, there has been a quite substantial migration of computer design capabilities to East Asia. One indication is the fact that companies like Apple, Compaq, and HP have designated some of their subsidiaries in Singapore with specific global product mandates and thus have transferred a variety of design capabilities.[201] Furthermore, the fact that overseas production now frequently occurs quite soon after the launching of new products implies that engineers in Asian subsidiaries have to be plugged into the companies' design debates (both on-line and face-to face) on a regular basis. The result is that key design information is now shared much more freely between the parent company and its overseas affiliates.

It is important to emphasize that the transfer of design capabilities has already moved to independent third parties. Take, for instance, those Taiwanese firms that today play a dominant role as suppliers of motherboards. While originally most of this production was OEM, the focus has now shifted to ODM with the Taiwanese firms responsible for design.[202] Another important development is the spread of "turnkey manufacturing" arrangements, where an American computer company, like Compaq, requires a Taiwanese firm such as Mitac to take over all the stages of the value chain, including design and process development, except for marketing.

All of this is to say that American firms have already accepted a certain transfer of design capabilities to Asia. This transfer has not been restricted to the boundaries of the firm, but also involves independent suppliers. American computer companies accepted this partial leakage of design capabilities in order to sustain and improve their access to the East Asian supply base and the region's increasingly important growth markets.

(5) Proximity between process and product development

A fifth, and final type of proximity relates to the close interactions that are necessary to harmonize process and product development. We have seen in chapter I how product and process development closely interact in the HDD industry. In short, production processes must constantly be adjusted to accommodate the unique specifications of a new design. Causality also works the

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[201] See our earlier discussion in chp. II of this study.

[202] Intel's failed atttempt to regain dominance for motherboard and chipset production shows that even a giant like Intel has difficulties competing in these highly volatile and time-to-market sensitive sectors.

other way: constant and iterative design adaptations are necessary in order to improve yields and accelerate time-to-market. HDD companies thus must excel at the simultaneous development of new products and new processes rather than undertaking them sequentially.[203] It is plausible to assume that such links are strongest if both functions are co-located.

In addition, there is a vast body of literature that shows that substantial barriers exist to the internationalization of R&D and that, as a result, R&D has been substantially less mobile than other value chain functions.[204] There is also substantial prima facie evidence to argue that, of all possible international locations for R&D, most locations in East Asia still lack fundamental prerequisites. So far, no location in Asia, including Singapore, has locational advantages for R&D.

Today, Singapore's main attraction is a good engineering support base for manufacturing that compares well with the U.S. Singapore also has a fairly well-developed precision parts industry, although the industry does not appear to have played a major role in the development of the Singaporean HDD industry.[205] Singapore still needs to overcome some important weaknesses before it can qualify as a location for HDD related R&D. This would require a capacity to mobilize and combine technological capabilities across a broad front, including magnetics, coding, precision engineering, and software. It takes a broad educational system, plus first-class research institutions, in order to develop such capabilities. Singapore also lacks an "entrepreneurial culture" that is necessary to foster quality applied research of the type that is needed for HDDs.

All of this appears to place a severe constraint on the broadening of international production networks. But we need to take a closer look. First, we need to ask whether close cooperation always necessitates co-location. There are indications that the spatial separation of manufacturing (in Singapore) and R&D (in the U.S.) has not been a serious problem.[206] The key to interaction between R&D and manufacturing is "time to fix," that is, the cycle from failure, to causes, to corrective action. This can be done remotely (i.e. via a computer network).

A second observation needs to be added. We saw before that engineers in Seagate's Bangkok facility are plugged into the company's design debates. This is despite the fact that

[203] For a general analysis, see Pisano and Wheelwright [1995].
[204] See, for instance, Patel and Pavitt [1990].
[205] I am indebted to Roger Bohn for this observation.
[206] Roger Bohn, Interview notes, November 10, 1995, p. 5.

Bangkok does not have any explicit product development mandate and that the main focus of this affiliate is on lower-end products. The main reason for this close information sharing is that without it Bangkok could not constantly adapt its production process to the requirements of changing design parameters. There is no doubt that, over time, such close information sharing will give rise to substantial learning effects in some of these overseas affiliates. The ultimate result is that more and more of the design knowledge will move overseas.

Third, while countries like Singapore currently lack a competitive advantage as a R&D location, that may well change for three reasons: (1) some of these countries are pursuing aggressive entry strategies into the aerospace industry which require the strengthening of a domestic R&D infrastructure; (2) the region is experiencing a rapid and armaments race and build-up of arms production, which is generating some spin-off effects on local R&D; and (3) Singapore, as well as Korea and Taiwan, are currently engaged in systematic attempts to improve the effectiveness of private and public R&D management. Indeed, Singapore has already implemented some important improvements in public innovation management.

Over time, there is likely to be increasing pressure to relocate some aspects of R&D to East Asia. Historical experience indicates that once this happens, the process will take on a momentum of its own. If certain elements of drive R&D are missing, firms can act as catalysts by bringing them in. At the beginning, all kinds of partial "island" solutions are possible. In short, while it is true that R&D is less prone to relocation than manufacturing, it is certainly not immobile and can be moved abroad.[207] The question, then, is not whether this will happen, but rather when and which locations worldwide will have accumulated sufficient design and R&D capabilities to qualify for such co-location.

Conclusions

This study has analyzed how the dynamics of global competition has changed the organization of international production in the electronics industry. In order to improve their specialization, electronics firms have established increasingly complex international production networks that extend not only beyond national boundaries, but also beyond the boundaries of the firm.

[207] Stopford [1995], p. 16.

The result is that an increasing share of the value-added has become externalized. Competitive success thus critically depends on a capacity to orchestrate such complex international production networks and to integrate them into the firms organization. The driving forces behind these changes in the organization of international production are more complex than is assumed by conventional economic theory. The need to reduce costs to offset an erosion of the home country comparative advantage is an important catalyst, but no more. Of equal importance are the penetration of contested growth markets as well as an improved access to clusters of specialized capabilities that are necessary to complement the firm's core competencies.

The message of this study can be summarized in the following three propositions:

- **First proposition**

As globalization of competition sweeps through the electronics industry, this has drastically increased the complexity and intensity of competitive requirements. Intense price competition needs to be combined with product differentiation in a situation where continuous price wars erode profit margins. Of at least equal importance is speed-to-market. The result is that competition centers around a firm's ability to build capabilities quicker and at less cost than its competitors. This is especially true in a knowledge-intensive industry like electronics. No firm, not even a dominant market leader, can internally generate all the different capabilities that are necessary to cope with these conflicting competitive requirements. This requires a shift from individual to increasingly collective forms of competition, "... from the legal entity known as the firm to the contractual network of firms tied together by mutual long-term interest."[208]

- **Second proposition**

Globalization of competition also has had important implications for the organization of international production: it is no longer sufficient to rely on equity investments and outsourcing of basic manufacturing functions. Electronics firms must now search for new ways to improve their specialization and are beginning to integrate their erstwhile stand-alone operations in individual host countries into increasingly complex international production networks. In essence, electronics firms are breaking down the value chain into discrete functions and locating these functions wherever they can be carried out most effectively, where they are needed to facilitate the penetration of important growth markets, and where this enables the firm to

[208] Stopford [1994], p. 21.

generate closer, faster, and more cost-effective interaction between different value chain stages across different locations.

This has accelerated the pace of geographic dispersion while at the same time increasing the complexity of the value chain activities that are moved overseas. We have seen that electronics firms have pursued a variety of geographic dispersion strategies and have documented the new patterns of specialization that are emerging in various sectors of the industry.

As for the increasing complexity of international production networks, this study has documented four important aspects: (1) New products are produced overseas much earlier than predicted by the product life cycle (PLC) theory. (2) The scope of international production has been substantially broadened and now covers all stages of the value chain, including some high value-added support functions. (3) Outsourcing has increased in importance and now covers a variety of high value-added support functions. And (4) systemic rationalization now cuts across national borders and covers a variety of cross-border linkages. To the degree that proximity advantages can be replicated abroad, this has further expanded the internationalization of the value chain. Once manufacturing moves abroad, there is a strong tendency for a concomitant migration of key support functions.

All of this implies that multinational enterprises in the electronics industry have considerably improved their capacity to manage the value chain across different time zones and continents. They have also improved their capacity to selectively source for a variety of specialized external capabilities, ranging from simple contract assembly services to quite sophisticated design capabilities. Over time, multinational enterprises have become much more demanding in their choice of locations and supply sources. Low labor costs are taken for granted, and alternative locations are judged by the quality of certain specialized capabilities firms require to complement their core competencies.

The spread of international production networks thus could have important positive welfare implications by facilitating the formation of local capabilities in an increasing variety of locations. Indeed, the study shows that American as well as Japanese electronics firms now have a vested interest in the development of a regional supply base in Asia. The main focus is on the formation of regional clusters of specialized capabilities. Undoubtedly, the stakes have been raised for local capability formation and regions now have to compete for investment on a global scale with other regions. Those regions that cannot provide such capabilities are left out of the circuit of international production. However, once a region has developed a critical mass of specialized capabilities, this is likely to lead to a virtuous circle. Participation in international production networks can thus help the regional cluster to establish the missing links to a variety of complementary assets.

- **Third proposition**

What, then, are possible implications for the U.S. electronics industry? How will the shift from partial to systemic globalization affect the competitiveness of this industry and its contribution to the nation's welfare?

Probably the most important finding of this study is that the shift from partial to systemic globalization has led to a creeping migration of higher value-added support activities that are essential for competitive success. Such leakages occur across the boundaries of the firm, but knowledge also moves to those foreign countries that have developed a critical mass of specialized capabilities that complement the core competencies of American firms. Sophisticated regulations on intellectual property rights can slow down this knowledge migration, but they cannot completely stop it. The forces of globalization are too powerful; once manufacturing moves abroad, there are almost irresistible pressures to relocate an increasing variety of higher value-added support services, including engineering support for overseas affiliates and suppliers as well as some elements of product and process development.

Many people are understandably concerned about these developments; rising unemployment and a loss of competitiveness are perceived to be the main threats. Under certain conditions, however, this process could also have important positive implications. Indeed, the spread of international production networks could act as a powerful catalyst for a concerted effort to upgrade the domestic production system. The real issue is to identify those conditions under which such positive effects are likely to emerge. The issue is thus not how to prevent the spread of international production networks, but how to shape it so that it will help to strengthen the U.S. electronics industry.

This study clearly indicates that the current success of American electronics firms, both in the computer and in the HDD industry, owes much to the establishment of export platform production networks in Asia. American electronics firms were able to improve their specialization by relying on a combination of the following three strategies: (1) an early redeployment of final assembly and testing activities to a few locations in East Asia; (2) the outsourcing of an increasing variety of value chain activities to Asian contractors, first in Japan, then in Korea and Taiwan, and now also in China and other Asian countries; and (3) a systematic rationalization of the international production networks (a shift from partial to systemic globalization) that have emerged as a result of these activities.

This has set in motion a virtuous circle. By re-deploying lower-end stages of the value chain to Asia, American electronics companies were able to concentrate on what they do best, i.e. on product design, the definition of global brand names, architectural standards, and the control of distribution channels. A focus on such higher stages of the value chain has generated high profit margins and thereby increased the disposable funds for R&D and investment. This has enabled American companies to remain market leaders through aggressive new product development and the creation of new and more sophisticated entry barriers. Relocation back home is thus no longer an option. Instead, conscious efforts need to be made to complement the spread of international production networks with a continuous upgrading of the domestic supply base.

For the project on the globalization of the HDD industry, this implies that research should focus on the trade-offs between the advantages of proximity (and co-location) and the advantages of geographic dispersal. This corroborates the focus chosen in the original project proposal. However, the project needs to move one step further and ask why, despite the proximity advantages to be gained from co-location at home, American disk drive manufacturers have all moved to international production.

As the present study shows, there are three possible solutions to this puzzle. First, the link between close cooperation and co-location may be somewhat looser than is normally assumed in the literature. There may thus be alternative and more indirect ways to achieve close cooperation that do not necessarily require physical co-location. Second, some forms of proximity may be less constraining than others to a redeployment of production overseas. Thus, it may actually be possible to reproduce these particular proximity effects at some of the foreign locations. And third, proximity matters and works best at home. Yet, there may be other more important concerns that force companies to shift to international production and to disregard the advantages that result from co-location. In addressing these three questions, the project could benefit from the distinction of five different types of proximity requirements that I have introduced in this study, each of which has very different implications for the co-location versus dispersion issue.[209]

[209] The five different types of proximity requirements I introduced earlier are (1) proximity to suppliers, (2) proximity to engineering support, (3) proximity between prototyping and volume manufacturing, (4) proximity to lead users, and (5) proximity between process and product development

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