

# **D**ANISH **R**ESearch **U**NIT FOR **I**NDUSTRIAL **D**YNAMICS

DRUID Working Paper No. 97-9

## **High-Tech Competition Puzzles. How Globalization Affects Firm Behavior and Market Structure in the Electronics Industry**

by  
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September 1997



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This paper draws on the analysis and empirical findings of the author's study *From Partial to Systemic Globalization. International Production Networks in the Electronics Industry*, prepared for the Sloan Foundation project on the Globalization in the Data Storage Industry, Graduate School of International Relations and Pacific Studies, University of California at San Diego, 1996, jointly published as *The Data Storage Industry Globalization Project Report 97-02*, Graduate School of International Relations and Pacific Studies, University of California at San Diego, and *BRIE Working Paper # 98*, the Berkeley Roundtable on the International Economy (BRIE), University of California at Berkeley, April 1997. Research for this study has been funded by the Alfred P. Sloan Foundation. I have benefited from discussions with Bengt-Ake Lundvall, Peter Maskell, Lynn Mytelka, Paolo Guerrieri, John Zysman, Peter Gourevitch, Roger Bohn and David McKendrick. Of course, I take full responsibility for the conclusions of this paper.

**Abstract**

This paper addresses two puzzles related to industrial dynamics and competition. The first of these puzzles is that a high degree of globalization may well go hand in hand with increasing concentration. I show that one of the most globalized sectors of the electronics industry, hard disk drives (HDD), also displays one of the highest degrees of concentration: multinational corporations, after all, may not be such effective "spoilers of concentration", as claimed by Richard Caves (1982).

The second puzzle that I address in this paper is that, despite an extremely high degree of concentration, this industry fails to act like a stable global oligopoly. So far, market share volatility has been restricted to the oligopoly members. There are however indications that this may change and that market contestability may improve.

The paper is organized as follows: I start with a discussion of the first puzzle, presenting evidence on globalization and concentration. I then address the second puzzle, linking high concentration to high volatility. Some possible explanations are reviewed in the third part of the paper, building on a conceptual framework introduced by G.B. Richardson (1996 and 1997). I analyze how globalization affects competition and distinguish forces that foster concentration and forces that are conducive for market disruption. I conclude with a few observations on what this implies for future research on the determinants of market structure and firm behavior.

### **Keywords**

competition; industrial dynamics; globalization; concentration; firm behavior; contestable markets; entry barriers; capabilities.

### **JEL Classification**

D21, L11, F23, L22, L86

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## **Preface**

DRUID welcomes international scholars in its research network and to publish their work in the DRUID working paper series. This paper by Dieter Ernst is a contribution to one of the themes given high priority in the research programme: Competition and industrial dynamics. It was presented at the DRUID Summer Conference (organised around this theme) that took place in Skagen early Summer 1997.

In the paper Dieter Ernst gives an interesting case-based criticism of traditional theory of competition. He shows that, in the market for hard disk drives, globalisation has actually led to a further concentration as measured by the market share of a handful of companies. Even more interesting is his second result that the dynamics of the industry do not in any way indicate less intensive competition, rather the opposite seems to be the case. Regular shake outs and changes in the ranking of the leading firms characterise the sector. This points to a need to develop measures of 'intensity of competition' which are independent from market structure.

A second interesting result is that, at least in this sector, globalisation goes hand in hand with growing geographical concentration to a handful of production sites, mainly located in Asia while ownership and control remains mainly in US-firms. It indicates that globalisation is a relative concept not to be interpreted too literally. In this case it refers to more geographically distributed production networks and to a dramatic redistribution in space of production activities from the US toward South East Asia.

Bengt-Åke Lundvall





## **Introduction: The Two Puzzles**

Far-reaching changes are occurring today in the competitive requirements of the electronics industry, and this has had important implications for firm behavior and market structure. The main driving force has been the globalization of competition: more than in any other industry, competition in the electronics industry cuts across national and sectoral boundaries. In order to compete in this industry, a firm must be present simultaneously in all major growth markets; dominance in a domestic market - even one as large as the U.S. - is no longer sufficient. This, in turn, requires a capacity to internalise on a global scale specialised assets and capabilities, such as technological knowledge, organizational competence, finance, production experience, supplier and customer networks and market intelligence that can lead to the timely development and to the 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.<sup>1</sup>

This has given rise to a rapid expansion of international trade and FDI, culminating in the spread of international production networks (IPN), with the result that the electronics industry arguably is among the most globalized industries today.<sup>2</sup> Take the example of the computer industry. Today, it is normal that the supply chain of a computer company spans different time zones and continents. For instance, final assembly most likely is dispersed to major growth markets in the US, Europe and Asia; microprocessors are sourced from the US; memory devices from Japan and Korea; motherboards from Taiwan; hard disk drives from Singapore; monitors from Korea, Taiwan and Japan; keyboards and power switch supplies from Taiwan, etc.... The electronics industry thus constitutes an excellent test case for research that inquires how globalization affects market structure and competition.

What are the consequences of globalization? The dominant view, based on the assumption of neo-classical trade theory, is that globalization will increase competition and hence will act as

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<sup>1</sup> This in line with the evolutionary, resource-based theory of the firm, based on Penrose, 1959; Nelson and Winter, 1982; Winter, 1982; Kogut and Zander, 1993; Langlois and Robertson, 1995; Foss and Christensen, 1996; and Andersen, 1996. For a recent overview, see Langlois and Foss, 1997

<sup>2</sup> For an in-depth analysis of the globalization patterns of the electronics industry, see Ernst 1997c; Ernst and O'Connor, 1992, chapters I and II; and Ernst, 1983.

a powerful equalizer both among nations and among firms.<sup>3</sup> One of the most sophisticated proponents of this neo-liberal globalization doctrine is Richard E. Caves. Take his widely quoted book Multinational Enterprises and Economic Analysis, first published in 1982 by Cambridge University Press, which since then has been re-printed eight times (Caves, 1982). Chapter 4 of this book deals with “Patterns of Market Competition” that result from the spread of international investment by MNEs. Caves argues that by increasing the number of buyers and sellers that can enter the contest in a given market, globalization is likely to decrease concentration and hence to intensify competition. The key sentences are: “...(T)he total number of MNEs (= multinational enterprises) has increased greatly in the past half century, (leading to) a growing population of both actual competitors in particular national industries and potential entrants to these industries” (Caves, 1982, p. 101). “...(T)he occurrence of new entry by MNEs tends to reduce the level of concentration, even considering that entry now is often affected by acquiring a local firm” (ibid., pages 102 and 103). “Thus, the recognition that MNEs sometimes enter via merger does not qualify out of existence the concentration-reducing effect of MNE entry.” This lends “... a bit of comfort regarding the MNE’s role as a spoiler of high concentration” (ibid., p. 102).

This may sound like a reasonably plausible proposition, especially for those economists who are still willing to accept some of the basic premises of neo-classical theory. Yet, as a brief look at the empirical evidence of industrial dynamics shows: “it ain’t necessarily so!” A high degree of globalization may well go hand in hand with increasing concentration. This is the first of the two high-tech competition puzzles that I address in this paper. I show that one of the most globalized sectors of the electronics industry, hard disk drives (HDD), also displays one of the highest degrees of concentration: multinational corporations, after all, may not be such effective “spoilers of concentration.”

With almost \$ 26 billion annual revenues, the HDD sector is a large and important sector of the electronics industry. It also stands out in terms of globalization and is heavily reliant on international production: Southeast Asia dominates with almost 2/3 of world production, while the U.S. share has fallen to 1%. Furthermore, globalization goes hand in hand with very high concentration: in 1995, the four market leaders controlled almost 85% of the world

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<sup>3</sup> For a popular version of this neo-liberal globalization doctrine, see Ohmae, 1991

market ( in terms of revenue shares). Following Bain, 1958 and Blair, 1972, one would have to conclude that the HDD industry constitutes a very tight 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 positions. Market leadership positions change hand in this industry at very short notice. This brings me to the second puzzle that I address in this paper: despite an extremely high degree of concentration, this industry fails to act like a stable global oligopoly. So far, market share volatility has been restricted to the oligopoly members. There are however indications that this may change and that market contestability may improve.

The paper is organized as follows: I start with a discussion of the first puzzle, presenting evidence on globalization and concentration. I then address the second puzzle, linking high concentration to high volatility. Some possible explanations are reviewed in the third part of the paper, building on a conceptual framework introduced by G.B. Richardson (1996 and 1997). I analyze how globalization affects competition and distinguish forces that foster concentration and forces that are conducive for market disruption. I conclude with a few observations on what this implies for future research on the determinants of market structure and firm behavior.



## **1. The first puzzle: globalization and concentration**

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 most tiny laptop PCs. The world market for HDDs today is almost \$26 billion.<sup>4</sup> By any standard, this is a large and important sector of the electronics industry.

This industry provides an excellent example for our first puzzle: under certain circumstances, globalization can go hand in hand with high and increasing concentration.

### **1.1. GLOBALIZATION**

Let us first look at three indicators of globalization: the international dispersion of production sites, employment and production networks.

#### **Production sites and employment**

The origins of the HDD date back to a research project begun in the San Jose laboratories of IBM in 1956. Until 1962, IBM was the only disk drive manufacturer. IBM's Winchester design, introduced in 1973, became the de facto standard during the 1970s. Until the early 1980s, almost all HDD production remained in the U.S., with limited additional production facilities in Japan and Europe. This began to change in 1982 when Seagate, only three years after its founding, decided to move a large part of its drive assembly to Singapore. One year later, in 1983, Seagate then moved on to establish a second affiliate in Thailand in the Bangkok metropolitan area. In 1984, Maxtor, another leading American HDD manufacturer, set its foot onto Singaporean soil.

Since then, all the leading HDD manufacturers have shifted most of their final assembly to Asia. In 1995, we find for instance that Conner Peripherals had three affiliates in Asia (in Singapore, Malaysia and China), Maxtor had three (in Singapore, Hong Kong and South Korea), and Seagate, which by then had become the industry leader, had six Asian affiliates (one each in Singapore, Malaysia, Indonesia and China, and two in Thailand).

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<sup>4</sup> DISK/TREND, Inc, 1995 DISK/TREND Report. Rigid Disk Drives, Mountain View, California, October 1995, p.9

The result is an extreme reliance on international production that goes well beyond what we find in other highly internationalized sectors of the electronics industry, like semiconductors and consumer electronics.<sup>5</sup> In 1995, less than 5% of the final assembly of HDDs has remained in the US, while Southeast Asia dominates with 64% of world production, based on units shipped.<sup>6</sup> Slightly less than half of the world's disk drives come from Singapore, with most of the rest of the region's production being concentrated in Malaysia ( primarily in Penang) and Thailand.

This heavy reliance on international production is also reflected in the geographic distribution of the HDD industry's employment. In 1995, roughly 67% of employment was in Asia, including 41% in Southeast Asia, while the share of the US was only 20%. While the U.S. share is still larger than for any other country, it is important to note that, taken together, Thailand (13%), Singapore and Malaysia (12% each) and China (10%), clearly absorb now the lion's share of the HDD industry's workforce.

### **International production networks and specialization**

Over time, HDD firms have progressively integrated their erstwhile stand-alone operations in individual host countries into increasingly complex international production networks (IPN)<sup>7</sup>: they 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 however are access to clusters of specialized capabilities and contested

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<sup>5</sup> On semiconductors, see Ernst 1983 and 1997c; on consumer electronics, see Bloom, 1992.

<sup>6</sup> By the end of 1996, the U.S. share of HDD final assembly has fallen to 1 percent. This and the following figures on employment are taken from: Gourevitch, Bohn and McKendrick, 1997.

<sup>7</sup> 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. 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? 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 the different elements of these networks hang together? For details, see Ernst, 1994; 1996; 1997a and 1997b; Ernst and Guerrieri, 1997; Ernst and Lundvall, 1997; and Ernst and Ravenhill, 1997.

growth markets, and the need to speed up response time to technological change and to changing market requirements.<sup>8</sup>

Consider a stylised international production network (IPN). As a first approximation, an IPN combines a lead-firm, its subsidiaries, affiliates and joint ventures, its suppliers and subcontractors, its distribution channels and VARs (=value-added resellers), as well as its R&D alliances and a variety of cooperative agreements (such as standards consortia). The lead company derives its strength from its control over critical resources and capabilities, and from its capacity to coordinate transactions between the different network nodes. One such source of strength for instance is the intellectual property and knowledge 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, such as engineering, research and development. The result is that an increasing share of the value-added shifts across the boundaries of the firm as well as across national borders.

Let us take a closer look at the IPN of Seagate, the current industry leader. Today, Seagate operates 22 plants worldwide: 14 of these plants, i.e. 64% of the total, are located in Asia.<sup>9</sup> Asia's share in Seagate's worldwide production capacity, as expressed in sq-ft, has increased from roughly 35% in 1990 to slightly more than 61% 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% in 1990 to 34% in 1995. During the same period, Europe's share declined from roughly 7% to slightly more than 5%.

Let us now look at the regional breakdown of Seagate's employment. Asia's share increased from around 70% in 1990 to more than 85% in 1995. Again, Asia's expansion occurs at the cost of the US. From 26% in 1990, the share of the US in Seagate's world employment fell to

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<sup>8</sup> For a detailed analysis, see Ernst, 1997d.

<sup>9</sup> Another widely quoted figure is that "...80% of Seagate's production..." takes place in five Asian countries: Singapore, Thailand, Malaysia, Indonesia and China (South China Morning Post, 5/16/95 and Asiaweek, 3/17/1995). The problem with this type of figure is that we are left in the dark about what is exactly measured. There is indeed reason not to 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.

11% in 1995, while Europe's share remains constant at a measly 4% 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.

The fact that Asia's share in employment is substantially higher than its share in capacity, while the opposite is true for the US, indicates a clear-cut division of labor: labor-intensive volume manufacturing has been shifted to Asia, while the US retains the high-end, knowledge-intensive stages of the value chain. Asia has absorbed most of the high-volume assembly activities and the production of low- and mid-range components. Precision component manufacturing and R&D however remain firmly entrenched in a few highly specialized regions like Bloomington and Minneapolis (both in Minnesota) and in California. For instance, 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.<sup>10</sup>

It is important to emphasize that the geographic dispersion of the value chain through IPN goes hand in hand with increasing geographic concentration. Most of Seagate's volume manufacturing is heavily concentrated in Asia. We need to add a second aspect: an extreme spatial concentration within East Asia. Let us start again with capacity figures. Slightly more than 92% of Seagate's capacity in Asia is concentrated in three locations: in Bangkok (almost 32%), Penang (more than 30%) and Singapore (a bit less than 30%). This may however change, as Seagate is now beginning to expand into other, less congested and cheaper locations like Korat in Thailand (currently with 6% of Seagate's Asian capacity), Shanghai/China and Batam Island/Indonesia .

A similar picture of intensive geographic concentration within Asia emerges from Seagate's employment figures. Almost 50% (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 right now is the centre for low labor cost volume manufacturing. Next comes Singapore with more than 27% (15,000), substantially more than Malaysia's 16% (9,000 people). These figures nicely show that Singapore increasingly takes on the role of a coordination centre,

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<sup>10</sup> This is in line with similar specialization patterns displayed by other leading HDD producers. Take for instance IBM: it makes media and wafers in the U.S. and Germany, heads in California, Mexico and Singapore, and assembles drives in Singapore, Thailand, Hungary and the U.K.



with the result that, in Singapore, the share of employees per sq-ft is much higher than elsewhere in the region. 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 and 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 include now 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 and China. Malaysian and Thai plants make components and specialize in partial assembly. Singapore is the centre 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.

## **1.2. CONCENTRATION**

The following indicators document that the HDD industry is one of the most highly concentrated sectors of the electronics industry and that its concentration continues to grow. Only computer operating systems, microprocessors and computer network equipment (routers, switches and hubs) are more highly concentrated, due to the de facto monopoly position that Microsoft, Intel and Cisco Systems occupy in these three sectors. Compared to these sectors however, the HDD industry is much more globalized.

One indicator of increasing concentration is the rapid decline in the number of worldwide drive manufacturers: the total has shrunk from 59 in 1990 to 24 in 1995, with most of the decline taking place after 1993.<sup>11</sup> In 1995, nine companies went out of business, and only three companies entered the fray, all of them in niche markets.<sup>12</sup> During the same year, Seagate, the current market leader, acquired Conner Peripherals, the company which, in

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<sup>11</sup> DISK/TREND, Inc, 1995 DISK/TREND Report. Rigid Disk Drives, Mountain View, California, October 1995, p.4

<sup>12</sup> 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.

1992, was the world market leader. Furthermore, two heavyweights, Hewlett Packard and DEC, left the HDD industry altogether during 1996.

If we look at market share data, we find that, by all standards, the HDD industry today is characterized by a very high degree of concentration. American companies are clearly in a dominant position: the top six HDD companies are all US-based firms.<sup>13</sup> Japanese companies only play a minor role: their market share (as a percentage of worldwide sales revenues) has peaked at 18% in 1990, and has fallen since then to less than 15% in 1994.

The latest data available on market share (again for revenue shares) show that, for 1995, the four leading disk drive manufacturers control almost 73% of the world market.<sup>14</sup> 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%.<sup>15</sup>

Concentration ratios are also quite high for the two main key components: heads and media.<sup>16</sup> In 1994 the largest 6 head manufacturers accounted for 78% of all HGAs shipped; the next 4 largest companies accounted for another 15%. U.S.-owned firms have 72% of the

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<sup>13</sup> 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 obviously is an American company, even though the firm manufactures most of its drives abroad. For Quantum, however, this definition becomes problematic, as Matsushita Kotobuki today 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 however 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 any longer an American company.

<sup>14</sup> The market shares of Seagate and Conner Peripherals have been lumped together, as Seagate has acquired Conner in September 1995, DISK/TREND, Inc. 1995 DISK/TREND Report. Rigid Disk Drives, Mountain View, California, October 1995,

<sup>15</sup> Disk/Trend Inc. figures, as quoted in Electronics Business Today, 11/95, p.41

<sup>16</sup> The supply of integrated circuits (ICs) for the HDD industry is dominated by specialized American producers. While the majority of these firms is relatively small, there has been a concerted effort by large TNCs to move into this highly profitable segment of the IC industry through mergers and acquisition. The search for economies of scale and scope in production, R&D and marketing exerts a powerful pressure towards increasing concentration. For details, see Eischen, 1997.

market and the Japanese 19%. The 10 largest companies have 93% of the market by volume.

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

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<sup>17</sup> Market shares are expressed by volume. Source: McKendrick, 1996.



## **2. The second puzzle: concentration and volatility**

The very high degree of concentration that characterizes the HDD industry, raises the question whether this industry is controlled by a tight oligopoly. This is an important issue. If we would have to conclude that this 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, indicating a low degree of market contestability. One might even argue that, as a tight oligopoly decreases competition, the pressure to globalize may slacken. This would be a perplexing finding: globalization has acted as a powerful force behind increasing concentration; yet once concentration reaches a certain level, it may in the end constrain further globalization.

Does high concentration lead to a tight oligopoly? One way to address this question is the structure-conduct-performance (SCP) theory. In this view market structure, as captured by concentration of sellers, is the primary determinant of both conduct and performance. Take one of the classic sources, Joe S. Bain's Industrial Organisation, published in 1958. Bain argues that high levels of sellers' concentration, protected by high entry barriers, will induce firms to engage in price collusion, which inevitably will constrain static efficiency allocation as well as learning.

According to Blair<sup>18</sup>, one of the leading proponents of the SCP theory, oligopoly begins when the four largest firms hold more than 25% of overall sales. Between 25 and 50%, this oligopoly is loose and unstable, but above 50%, 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.<sup>19</sup> He distinguishes three types of oligopolistic market structures: "very highly concentrated oligopolies", where the top eight firms control 90% of the market and the top four 75%; "highly concentrated oligopolies", where the respective shares are 85-90% and 60-65%; and "high-moderate concentrated oligopolies", where corresponding control is 70-85% and 50-

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<sup>18</sup> Blair [1972].

<sup>19</sup> Bain [1958].

65%. 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 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 leader, 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.<sup>20</sup> In 1992, Conner Peripherals was the market leader with 24%. Yet, one year later, in 1993, Quantum had leapfrogged both Conner and Seagate to become No. 1: from 15.3% in 1992, Quantum increased its market share to nearly 21% in 1993 and 23% in 1994. Conner Peripherals in turn fell back to the third position, and has seen its market share eroding to 16% in 1994. 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.

Furthermore, successful entry did occur, albeit in an indirect manner. Probably the most interesting case is that of Matsushita Kotobuki (MKE), an affiliate of the powerful Matsushita group. Since 1984, Kotobuki has contended itself for many years to remain an apparently humble contract manufacturer for Quantum, one of the leading American drive producers. Today, MKE produces Quantum's full product range, including the highly profitable high-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.

A second example of successful entry is the powerful Korean Hyundai group which, in 1995, has acquired 100% ownership of Maxtor, one of the industry's pioneers and leaders. Finally, a third example is the fate of Micropolis, once an American industry leader. Micropolis is now

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<sup>20</sup> 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, page 50). For instance, shipments by IBM are non-captive, except for drives sold with systems made by the parent company or other subsidiaries.

owned by a publicly owned Singaporean business group that is aggressively pursuing a product differentiation strategy based on heavy R&D investments.

In short, new entry did occur, despite the high degree of concentration. We are thus faced with a second 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.





### 3. Possible explanations: the dynamics of competition

How do we explain the two puzzles that characterize the impact of globalization on competition? Let us first briefly look at the theoretical literature.<sup>21</sup> The structure-conduct-performance (SCP) paradigm has lost much of its earlier grip on the debate. William J. Baumol's theory of "contested markets", first introduced in 1982, has been an important catalyst. Baumol argues that even highly concentrated industries will be forced to price competitively, provided they face the "discipline of potential hit-and run entry." The crux of this analysis is the existence of "sunk costs": the higher the sunk cost, the less likely is the market to be contestable. This would have implied that high-tech industries, with their very high "sunk costs" due to R&D, would have been less prone to contestability.

It became however soon clear that globalization could change the picture. Globalization implies that even markets that are characterized by substantial sunk costs, may become contestable: foreign firms who have already incurred the necessary sunk cost in their home markets, may very well be able to enter such markets. This has provoked some counter-arguments that come to very different conclusions. Some argue that, as globalization leads to market expansion, sunk costs and scale economies increase apace, further increasing concentration. Take for instance John Sutton's important study Sunk costs and market structure, published in 1991. Sutton demonstrates that high concentration may well square with intense price competition. Paradoxically enough, such price wars may cause higher concentration by forcing out marginal producers and by reducing margins for potential entrants. This, in fact, has been the case for the HDD industry: prices have been falling about 30% per year for more than a decade, fostering increasing concentration.

In short, the deeper we dig in the literature, the more we find that we still know very little about how globalization affects market structure and firm behavior. This paper attempts to move a bit further ahead into this uncharted territory.<sup>22</sup> I use as a starting-point a recent short, but extremely stimulating paper by George B. Richardson (Richardson 1996) which argues for a radical revision of competition theory. Competition for given products is only

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<sup>21</sup> For a useful review, see UNCTAD, 1997, chapter IV

<sup>22</sup> For similar attempts, see Richardson 1997 (on the software industry); Bresnahan and Malerba, 1997 (on the computer industry); Langlois and Steinmueller, 1997 (on the semiconductor industry); and Lee and Lotz, 1997 (on the hearing instrument industry).

the tip of the iceberg: “We concentrate too much .. on monopoly revenue being obtained by the restriction of supply, and as threatened by entrants who might increase that supply.” (Richardson 1996, p.4) Yet, competition in reality centers on development and innovation. Competitive success depends on whether a firm is able to bring to the relevant markets a new product right on time: being the first can bring huge profits, but being late is a disaster. This has led to a dramatic increase in the pace of structural transformation and has generated new challenges for firm strategies and government policies that are not touched upon by conventional competition theory.

In order to understand the factors that shape competition, we need to identify basic characteristics of an industry (Richardson, 1997, part I). This is what I will do for the HDD industry. More specifically, I distinguish forces that foster concentration and forces that are conducive for market disruption. Among the first, I consider the role of scale economies and the heavy sunk cost due to very complex capability requirements. Among the latter, I consider three sources of market disruption: periodic spurts of rapid capacity expansion due to extremely short product cycles; a complex supply chain that leads to periodic shortages in key components; and highly volatile demand patterns and trajectory-disrupting innovations. The combination of stabilizing and disrupting forces creates a highly complex mix of competitive requirements where price and non-price forms of competition are closely intertwined.

### **3.1. PRODUCT FEATURES AND COMPETITION**

The key to our analysis are specific features of the product mix that characterize a particular industry sector. Industrial economists distinguish homogeneous (standard) and differentiated (unique) products, in terms of the complexity of their technology and the demand patterns they are facing.<sup>23</sup> Homogeneous products are based on widely accessible and mature technology and are thus easy to replicate. Changes in demand patterns are fairly predictable and interactions with customers plays a role only at the margin. Differentiated products, on the other hand, are based on new technology whose design features are still fluid and are thus difficult to replicate. This is due to the high entry barriers that result from the high R&D outlays required. Close interaction with customers is a critical prerequisite for success. It is

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<sup>23</sup> See, for instance, Baumol, Panzer and Willig (1982) and Nilsson (1996).

argued that different market structures will result from these different product features: for differentiated products, firms can charge premium prices, while for homogeneous products, price competition is the over-riding concern.

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 loses in importance. HDDs are archetypal "high-tech commodities": they combine the characteristics of mass production with extremely short product cycles and periodic trajectory-disrupting innovations.<sup>24</sup> Mass production implies large investment thresholds that are necessary to reap economies of scale and scope.<sup>25</sup> Short product cycles imply the rapid depreciation of plants and equipment and of R&D. Only those companies can survive that are able to get the right product at the right time to the highest volume segment of the market. Entering a new market right 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: huge sunk costs are necessary in order to generate a constant stream of new products and architectural designs. But even this does not guarantee success: established leadership positions can no longer be taken for granted, and the target of competition becomes fuzzy and can change at any time.

Due to the rapid pace of change of IT, trajectory-disrupting innovations occur more frequently. First-mover advantages thus matter less, and leaders in a particular market are under constant threat of displacement: "... (W)here the scope for innovation is particularly

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<sup>24</sup> Ernst, 1997c.

<sup>25</sup> On the role of economies of scale and scope, Chandler, 1990, remains the most authoritative source. Economies of scale and scope in the computer industry are analyzed in Flamm, 1988 and 1990; Ferguson, 1990; Ernst and O'Connor, 1992; and Ernst, 1997c.

high, a fresh approach may often prove successful and past success and experience can trammel as well as support. Only myopia can lead one to believe that a commanding position is unassailably and continuously secure. ... The established firm, however mighty it may seem, can be brought down, or at least for a time eclipsed, by complacency, by arrogance, or simply by the fact that market opportunities or technical possibilities change in a way that favours others with different mind-sets, more relevant experience, more appropriate market connections, or simply greater luck.” (Richardson, 1997, p.7).<sup>26</sup>

The result is that, even if a firm has captured the lion’s share of a particular market, it may have won a battle but not the war. “Its competitors will already be planning to bring out a better competing product and the firm itself, for the sake of its survival, will already be planning its own next move.”(Richardson, 1997, p.6) This extreme compression of the product life cycle and a concomitant increasing uncertainty is in fact a general trend that leads to potential market volatility in many industries. Take for instance the situation in the copier industry which is certainly not among the leading-edge high-tech industries: “..Both the pace and the acceleration of innovation are startling; nay terrifying....No-one can predict the ... range of skills which will need to be amassed to create and take advantage of the next revolution but one (and thinking about the next but one is what everyone is doing. The game is already over for the next).”<sup>27</sup>

In short, the accelerated pace of innovation has led to a constant threat of displacement for market leaders. They need to respond to this threat early on, and, if possible, in a pre-emptive manner. The key to competitive success is a firm's ability to complement price competition with product differentiation and speed-to-market. What really matters for competitive success in the HDD industry are the substantial investments in the formation of a firm's technological and organizational capabilities. These changes in the economics of competition have had far-reaching implications for firm behavior as well as market structure. They explain why high concentration can go hand in hand with high market volatility.

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<sup>26</sup> For a similar argument, see Christensen, 1994 and Christensen and Rosenbloom, 1995.

<sup>27</sup> Bob Anderson, Director, Rank Xerox Research Centre, Cambridge Laboratory, “R&D Knowledge Creation as a Bazaar Economy”, paper presented at OECD-IEE workshop on Competition and Innovation in the Information Society, 19th March, 1997 (Anderson, 1997).

The result is that the focus of competitive strategy, today, is on the management of change much more than on protecting the status quo.

### **3.2. FORCES THAT FOSTER CONCENTRATION**

#### **a) Scale economies**

Scale economies are of critical importance in the HDD industry, and they keep increasing 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, molds and dies that are required to make the various high-precision components and parts that go into the 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.

Minimum economies of scale in the HDD industry apparently have grown very rapidly over time. For instance, in 1989 an annual production capacity of between 900,000 and 1 million units<sup>28</sup> was regarded as economic scale<sup>29</sup>: for instance, Seagate's Bangkok production facility then had a registered annual production capacity of 940,000 units. In that same year, Matsushita Kotobuki's new production line for 3.5" drives in Japan was designed to produce 1.2 million drives p.a., making it one of the largest facilities worldwide.<sup>30</sup> 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.<sup>31</sup> Take the 1996 capacity figures reported by Maxtor, a U.S.-based HDD producer which is now wholly owned by

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<sup>28</sup> 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 or disk stack.

<sup>29</sup> Ernst and O'Connor [1992], p.194.

<sup>30</sup> Note that Matsushita Kotobuki, already since 1984, has been a contract manufacturer for Quantum Corp. which currently is the third largest vendor of HDDs.

<sup>31</sup> This reflects the fact that, with almost \$ 26 billion worldwide sales revenues, the HDD industry has become a major industry. Capacity requirements in this industry are driven by a very rapid growth of demand: unit worldwide shipments increased by 35% in 1994, almost 26% in 1995, and are projected to increase by around 18% in 1996.

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 orders of magnitude are reported for Maxtor's new facility in Dalian, China, i.e. 16 million units per year.<sup>32</sup>

### **b) 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% a year.<sup>33</sup> 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 like magnetics, coding, and electronics. They also need to 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 that control the flow of information to and from those disks. This requires a variety of high precision engineering capabilities, for instance for the production of miniature motors that need 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 ICs. In addition to some of the most sophisticated component manufacturing technologies, the final assembly of these drives requires leading-edge automation techniques, such as surface-mount technology.

Yet, while manufacturing matters, it is only part of the story. Competitive success in this industry 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 these drives. Finally, leading-edge software capabilities are an equally important prerequisite for developing a viable HDD industry. Both

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<sup>32</sup> COMLINE Daily News Service From Korea, March 6, 1996.

<sup>33</sup> DISK/TREND, Inc, 1995 DISK/TREND Report. Rigid Disk Drives, Mountain View, California, October 1995, p.6.

architectural design and software capabilities have been of crucial importance as instruments for product development and differentiation strategies - these are strengths of American companies and may constitute an important reason for their continuous market leadership.<sup>34</sup>

### **3.3. FORCES THAT ARE CONDUCTIVE FOR MARKET DISRUPTION**

In the HDD industry, scale economies and sunk costs have combined to increase concentration. At the same time, there are powerful counter-vailing forces that give rise to periodic disruptions of established market positions. Such disruptions can be traced back to three main sources: a) periodic spurts of rapid capacity expansion due to extremely short product cycles; b) a complex supply chain that leads to periodic shortages in key components; and c) highly volatile demand patterns and trajectory-disrupting innovations.

#### **a) Extremely short product cycles**

Competition in the HDD industry is driven by the speed of new product introduction, with the result that product life cycles become shorter and shorter. One important characteristic of this industry are its very short product cycles: 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.<sup>35</sup> This leads to a rapid depreciation of plants and equipment and of R&D. Like semiconductors, the HDD industry thus falls prey to a "scissors effect" between rapidly increasing fixed capital costs and an accelerated depreciation of its assets.<sup>36</sup> The result is that speed-to-market is of critical importance: a firm must be able to ramp up production quickly to competitive yields and quality.

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

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<sup>34</sup> For an excellent analysis of the role that architectural design plays in this industry relative to component innovations, see Christensen [1993]

<sup>35</sup> Product cycles for HDDs have been drastically cut. For high-end products such as drives for servers and mainframe computers, they have fallen from 24 months to about 12 months. They are considerably shorter for desktop applications, where new drive generations are introduced about every nine months, and for laptop PCs where the product cycle has been reduced to roughly six months. 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 this industry, like for instance multimedia home computers, product cycles are now almost as short as those for fashion-intensive garments.

<sup>36</sup> For an early analysis of this scissors effect in the semiconductor industry, see Ernst, 1983, chapter I.

first supplier.<sup>37</sup> 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, a capacity to exit rapidly becomes as important as a capacity for rapid capacity expansion. Fast ramping-up and ramping-down hang together and require an incredibly short response time to changes in markets as well as in technology.

Short product cycles thus are an important source of market disruptions. 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, this leads to periodic price wars. 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.<sup>38</sup> Both have become inseparable.

#### **b) A complex supply chain**

In terms of its logistical requirements, the HDD industry is probably the most demanding sector in the electronics industry: it requires a wide variety of high-precision components and sub-assemblies. Their 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. 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.

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<sup>37</sup> " 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." William Roach, executive vice president for worldwide sales at Quantum Corp. of Milpitas, CA., quoted in: Electronics Business Asia, January 1995, p.35.

<sup>38</sup> Porter, 1985 for instance assumes that price competition and product differentiation can be neatly separated. For a similar assumption, see Kogut, 1985a and b.



The case of Maxtor illustrates how deadly this reliance on outsourcing can be. This company which used to be one of the leading US suppliers of HDDs, has experienced a dramatic fall in market share and has been acquired by the Korean Hyundai group in 1995. Maxtor's main weakness has been a lack of strong in-house circuit design expertise. In a recent 10K report, Maxtor explains how two serious component supply problems have contributed to its decline<sup>39</sup>: "The Company is experiencing a shortage of media.... The shortage is anticipated to continue at least through [the second calendar quarter of 1996]." Maxtor also faces 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 600,00."

#### **c) Volatile demand patterns**

The main market for HDDs is the computer industry. As suppliers of an intermediate input to the computer industry, HDD firms compete for design-ins by computer companies. 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: a threat from competing technologies and break-through innovations in the drive design and in component technology that would drastically improve disk drive capacity, performance and cost. There are a number of competing technologies: optical storage offers higher capacity, tape drives lower cost, RAM chips far better speed, and flash EEPROMs more durability for portable applications.

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

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<sup>39</sup> 10-K, Maxtor Corp., fiscal year 1995.

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."<sup>40</sup>

Break-through innovations in architectural design and in component technology have periodically caused quite serious turmoil in the HDD industry.<sup>41</sup> No HDD company thus can 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 to sustain the status quo, there is a danger that the HDD manufacturer may be locked into a trap of obsolete architectural designs. If however our company succeeds to broaden its customer base to include computer companies that are intent to develop 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: 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.<sup>42</sup>

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 thus are of critical importance. 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, broadening the scope for market disruptions.

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<sup>40</sup> "Technical Review", in: DISK/TREND, Inc, 1995 DISK/TREND Report. Rigid Disk Drives, Mountain View, California, October 1995, p.27

<sup>41</sup> For an excellent analysis, see Christensen [1993]

<sup>42</sup> Christensen [1993] , pages 21 and 22

## Conclusions

This paper has shown that, in contrast to conventional wisdom, globalization may well increase concentration and market power. It has been argued that this perplexing result is likely to occur in any industry which, like the HDD industry, is characterized by significant scale economies and sunk costs. As globalization proceeds in such high-tech industries, sunk cost and scale economies increase apace, further increasing concentration. In addition, ferocious price wars (with prices falling about 30% per year for more than a decade) have further added to high concentration, by forcing out marginal producers and by reducing profit margins for new potential entrants.

The paper also identifies a second high-tech competition puzzle: an extremely high degree of concentration may not necessarily be equated with a stable and tightly-knit oligopoly, unconstrained by the competitive discipline of potential entry. Three sources of market disruption typically characterize heavily globalized high-tech industries: periodic spurts of rapid capacity expansion due to extremely short product cycles; a complex supply chain that leads to periodic shortages in key components; and highly volatile demand patterns and trajectory-disrupting innovations.

These two findings clearly indicate that we can no longer take for granted some of the earlier credos of competition theory. As competition increasingly transcends national and sectoral boundaries and hence becomes global, we need to take a fresh look at the determinants of market structure and firm behavior. We need an analysis that takes into account the possibility of unexpected and radical transformation that is due to the extremely rapid change in technology and markets: “The fact that we cannot, in the nature of things, predict changes that will radically transform the industry’s landscape should not lead us to doubt that changes will come about; only ignorance of history, and poverty of imagination, would lead us to that conclusion.” (Richardson, 1997, p.9)

More in-depth empirical research is required that addresses three sets of questions: i) To what degree can one generalize the findings of this paper, i.e. how does the HDD industry differ from other knowledge-intensive manufacturing and service industries? ii) What conclusions can one draw from this analysis for the impact of globalization on market

structure and competition in the great bulk of industries that are less knowledge-intensive and hence less prone to sunk costs? And, finally, iii) what are the normative implications for government policies and firm strategies that would facilitate attempts to increase market contestability?

In the final analysis what really matters is the dynamics of change. We need an analysis that explicitly distinguishes different periods in the development of an industry. Such an evolutionary theory of competition will show that the relationships between market structure, conduct and performance undergo considerable changes over time. The result is that, for each of these periods, different sets of strategies and policies are required in order to foster contestable markets.

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# Danish Research Unit for Industrial Dynamics

## *The Research Programme*

The DRUID-research programme is organised in 3 different research themes:

- *The firm as a learning organisation*
- *Competence building and inter-firm dynamics*
- *The learning economy and the competitiveness of systems of innovation*

In each of the three areas there is one strategic theoretical and one central empirical and policy oriented orientation.

### ***Theme A: The firm as a learning organisation***

The theoretical perspective confronts and combines the resource-based view (Penrose, 1959) with recent approaches where the focus is on learning and the dynamic capabilities of the firm (Dosi, Teece and Winter, 1992). The aim of this theoretical work is to develop an analytical understanding of the firm as a learning organisation.

The empirical and policy issues relate to the nexus technology, productivity, organisational change and human resources. More insight in the dynamic interplay between these factors at the level of the firm is crucial to understand international differences in performance at the macro level in terms of economic growth and employment.

### ***Theme B: Competence building and inter-firm dynamics***

The theoretical perspective relates to the dynamics of the inter-firm division of labour and the formation of network relationships between firms. An attempt will be made to develop evolutionary models with Schumpeterian innovations as the motor driving a Marshallian evolution of the division of labour.

The empirical and policy issues relate the formation of knowledge-intensive regional and sectoral networks of firms to competitiveness and structural change. Data on the structure of production will be combined with indicators of knowledge and learning. IO-matrixes which include flows of knowledge and new technologies will be developed and supplemented by data from case-studies and questionnaires.

***Theme C: The learning economy and the competitiveness of systems of innovation.***

The third theme aims at a stronger conceptual and theoretical base for new concepts such as 'systems of innovation' and 'the learning economy' and to link these concepts to the ecological dimension. The focus is on the interaction between institutional and technical change in a specified geographical space. An attempt will be made to synthesise theories of economic development emphasising the role of science based-sectors with those emphasising learning-by-producing and the growing knowledge-intensity of all economic activities.

The main empirical and policy issues are related to changes in the local dimensions of innovation and learning. What remains of the relative autonomy of national systems of innovation? Is there a tendency towards convergence or divergence in the specialisation in trade, production, innovation and in the knowledge base itself when we compare regions and nations?

**The Ph.D.-programme**

There are at present more than 10 Ph.D.-students working in close connection to the DRUID research programme. DRUID organises regularly specific Ph.D-activities such as workshops, seminars and courses, often in a co-operation with other Danish or international institutes. Also important is the role of DRUID as an environment which stimulates the Ph.D.-students to become creative and effective. This involves several elements:

- access to the international network in the form of visiting fellows and visits at the sister institutions
- participation in research projects
- access to supervision of theses
- access to databases

Each year DRUID welcomes a limited number of foreign Ph.D.-students who want to work on subjects and projects close to the core of the DRUID-research programme.

**External projects**

DRUID-members are involved in projects with external support. One major project which covers several of the elements of the research programme is DISKO; a comparative analysis of the Danish Innovation System; and there are several projects involving international co-operation within EU's 4th Framework Programme. DRUID is open to host other projects as far as they fall within its research profile. Special attention is given to the communication of research results from such projects to a wide set of social actors and policy makers.

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