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Introduction

Economics is about the allocation of resources to alternative uses to improve economic performance. Given their professional training, the vast majority of economists think of the market as the social institution that does, or at least should, accomplish this task. In conventional theory, the role of "the firm" is, or, normatively, should be, to respond to the dictates of market forces in making its allocative decisions. Although for some firms, and for some activities, the firm may play such a passive role in the allocation of resources, such a perspective does not accord a significant role to management in the allocation of resources, and renders business activity in general derivative of market forces in the economy as a whole.

In assuming the position of economics editor for the second edition of the International Encyclopedia of Business and Management (IEBM) and for the first edition of the IEBM Handbook of Economics, I have sought to draw upon the expertise of economists (and some people in related social sciences with expertise on economic subjects) who do not share this conventional point of view. In particular, I have solicited entries from people who concur that in one way or another, for better or for worse, business enterprises, through their allocative decisions, play a role in determining the development of productive capabilities in the economy, and, hence over time, the alternative productive uses to which resources can be allocated. Some entries have taken up this theme directly, while other entries have sought to explain the economic and social environments in which such economic activity on the part of business enterprises takes place. In all the entries, the goal has been to present clear and logical economic analysis on major economic issues, with an explicit

recognition of the centrality of business activity and its management to the operation and performance of a modern economy.

In putting together the collection of entries that appear in this Handbook, I did not have to start from scratch. My predecessor as IEBM economics editor, Francis Fishwick, with input from general IEBM editor, Malcolm Warner, had already gathered together a large number of entries for the first edition of IEBM. All of the biographical essays, save that of Edith Penrose, had been produced for the first edition of the IEBM, and I was in general agreement with the list of economists for whom my predecessor had secured biographies. As the new editor, I selected those analytical entries from the first edition of the IEBM that best fit my vision of the Handbook, and provided the authors with comments for revision and updating. About one-third of the analytical essays included in this Handbook were revised from the first edition of the IEBM. In soliciting new entries, I placed particular emphasis on ensuring that issues of innovation, industrial dynamics (generally and with reference to particular industrial sectors), income distribution, and international institutions would be well represented. Although a few entries that I had wanted to be produced for the Handbook failed to materialize, in general, as an editor, I had remarkable cooperation from authors, old and new. I would also like to acknowledge the considerable time and energy that So-Shan Au at Thomson Learning put into this project, as well as valuable secretarial assistance provided by Michèle Plu and Wendy Burwood at INSEAD.

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Electronics industry

- 1 Relevance
- 2 Historical perspective: the flagship model of industrial organization
- 3 Competition puzzles: empirical evidence
- 4 Possible explanations
- 5 Key questions for ongoing research

Overview

This article highlights fundamental changes in the electronics industry that have transformed its competitive dynamics and industrial organization: a high and growing knowledge intensity; the rapid pace of change in technologies and markets; and extensive globalization. That explosive mixture of forces has created two inter-related puzzles. The first puzzle is that a high degree of globalization may well go hand in hand with high and increasing concentration. This runs counter to the dominant view, based on the assumption of neo-classical trade theory, that globalization will increase competition and hence will act as a powerful equalizer both among nations and among firms. Multinational corporations, after all, may not be such effective 'spoilers of concentration', as claimed by Richard Caves (1982). The second related puzzle is that this industry fails to act like a stable global oligopoly, even when concentration is extremely high: market positions are highly volatile, new entry is possible and not even market leaders can count on a guaranteed survival.

Defining the *electronics industry* is tricky. Recent research (e.g. Afuah 1997) has shown that products are insufficient to define an industry when specialized suppliers exist; when there is complex market segmentation and abrupt change in demand patterns; when there is intense and unpredictable technical change; and when financial institutions accelerate the pace of industrial restructuring and increase uncertainty. All of these conditions prevail in

the electronics industry – key sectors are in turmoil, with sectoral boundaries changing incessantly. For lack of a better alternative, however, we still have to use products and key technologies as a proxy definition.

Most studies have focused on the hardware side, i.e. electronics equipment and components. We include in addition software, information services and a variety of newly emerging markets that result from the convergence of digital information, audio and video, and communication technologies (e.g. Internet services). This broad definition reflects a fundamental shift in the centre of gravity of value generation (as defined in Lazonick 1991) away from hardware and component technology towards architectural design standards, software and knowledge-intensive services. These changes in technological and competitive dynamics have further increased the already high knowledge intensity and exposure to globalization, thus posing new challenges for industrial organization. The electronics industry thus is a good test case for studying competitive dynamics in a globalizing world.

We first explain why it matters to understand the economics of the electronics industry. Section 2 provides a historical perspective on how the structure of the electronics industry evolved, centred around a *symbiotic* relationship between computers and semiconductors. We briefly sketch the story of how IBM created the flagship model of industrial organization, by relying on global production networks (GPN) for manufacturing services, and by outsourcing the PC operating system (to Microsoft) and the microprocessor design (to Intel). Section 3 reviews empirical evidence on the electronics industry's competition puzzles. Some possible explanations are reviewed in section 4 of the entry: we distinguish sources of concentration and sources of market volatility. Finally, in section 5 we highlight key questions addressed in ongoing research that can further clarify this subject.

I Relevance

Understanding what forces shape the competitive dynamics of the electronics industry is not just an issue for sector specialists. Addressing this question has broad ramifications for debates on possible new sources of economic growth.

There is a broad consensus that the electronics industry is of critical importance for enhancing productivity, competitiveness and long-term growth. This strategic industry argument is based on various propositions. One is that the industry has followed, for more than 25 years, 'Moore's Law', laid down by Gordon Moore, co-founder of Intel: every 18 months or so, the price of computing power has been halved. This change has provided a powerful incentive for a pervasive digitalization of economic transactions. A second proposition states that, provided appropriate organizational innovations are in place, the spread of computer-based information and communications technology (ICT) can drastically increase productivity across all stages of the value chain, and hence enhance a society's economic growth and welfare.

A third proposition emphasizes the potential of ICT to reduce the friction of time and space, a change that could fundamentally alter the nature of economic growth. Proponents of the 'New Economy', for instance, argue that ICT has accelerated the pace of change in economic structures and institutions, reducing the barriers to non-inflationary growth (OECD 2000). Strong expectations also exist with regard to the spatial impact: it has been argued for instance that IT enhances both the incentives and the possibilities to codify knowledge, which facilitates international knowledge diffusion, thus broadening the scope for globalization (e.g. David and Foray 1995). A fourth proposition finally highlights market failure: due to the massive externalities involved, investments are typically characterized by a gap between private and social rates of return (Arrow 1962). This requires corrective policy interventions that provide incentives, as well as the necessary infrastructure, support services and human resources.

These issues rank high on the priority lists of management and policy debates. Until the

early 1990s, the automobile industry provided the role model with its shift from 'Fordist' to 'lean production'. This is no longer the case. Developments in the electronics industry are now the primary determinants of a 'New Industrial Organization' model (e.g. Chandler *et al.* 1998). Unrivalled in its degree of globalization and in its exposure to global competition, the electronics industry has become the most important breeding ground for changes in firm organization and industry structure.

Management debates for instance focus on new approaches to global supply chain management developed in the electronics industry, such as the BTO (built-to-order) production model of Dell Computer Corporation. The main concern is to reduce the high cost of coordination that results from extensive geographic dispersion, multiple sourcing, duplication of tasks and excess capacity. Equally important is that suppliers are now confronted with much more demanding performance, efficiency and time-to-market requirements. Effective time management is of the essence: Inventory turnovers have become a critical indicator of competitive success, in addition to profits and market capitalization (Fine 1998). Some observers claim that this constitutes a new 'American Model of Manufacturing' that is now being extended beyond electronics to a broad range of information-intensive and time-sensitive sectors that encompass food and garments as well as cars and aircraft (e.g. Florida and Sturgeon 1999; Kenney 2000).

Policy debates both in the USA and in the European Union (EU) highlight the role of ICT-based organizational innovations as major new sources of economic growth. The same is true for Asia's policy debates on post-crisis industrial upgrading. However, there is still substantial confusion. Most of the debates are centred on simple dichotomies that juxtapose for instance information (or knowledge, or network, or simply post-modern) society against industrial society; flexible specialization against mass production; and Wintelism against Fordism (e.g. Castells 1998; Borras 2000). Such *reductionist* concepts are inadequate to explain the complex processes of organizational evolution in industry structure and firm behaviour that have transformed the electronics industry. A brief review of how the

structure of the electronics industry evolved can help to clarify these issues.

2 Historical perspective: the flagship model of industrial organization

It was during the late 1940s, and due to the development of the mainframe computer and the invention of the transistor, that the USA established a firm worldwide leadership in the electronics industry. Despite important challenges, especially Japan's catching up in DRAM (dynamic random access memories), later followed by Korea, Taiwan and Singapore (e.g. Ernst and O'Connor 1992; Hobday 1995; Ernst 1994, 1997, 2000c; Mathews and Cho 2000), US leadership has remained remarkably stable.

Two explanations are offered in the literature (e.g. Langlois and Steinmueller 1999; Bresnahan and Malerba 1999). First, a rapid diffusion of basic technologies arguably has created a pool of independent specialized suppliers, the so-called semiconductor merchant firms that aggressively pursued international market-share expansion and technology development. A second related argument is that rapid technology diffusion in the USA reflects peculiar features of its competitive dynamics and industrial organization that were very different from those in Europe and Japan. Three features are normally highlighted: (1) a *symbiotic* relationship between computers and semiconductors; (2) government policy focuses on performance-orientated procurement; and (3) incentives that facilitate the entry of specialized supplier start-up companies.

These arguments have some plausibility. But they fail to tell the full story: the proliferation of specialized suppliers did not occur in isolation. While legally independent, these firms were closely interacting with large corporations (initially, AT&T and IBM, but later on including companies like Hewlett Packard and Intel) that acted as flagships of emerging production networks. Those networks emerged first within the USA, but were soon extended internationally. An early exposure to globalization is arguably one of the important distinguishing features of the US

semiconductor industry that explains its early leadership (e.g. Tilton 1971; Ernst 1983). The same is true for its twin sister, the computer industry.

Computers

Let us briefly look at how IBM created the flagship model of industrial organization by relying on global production networks (GPN) for manufacturing services. Similar stories can be told for other major flagship companies (e.g. Ernst 1997; Borrus *et al.* 2000). IBM's move toward an integrated, worldwide operation dates back to 1949, when its World Trade Corporation was established. IBM's 'interchange plan' in Europe during the 1950s probably is one of the first systematic attempts to optimize its international operations by establishing a transatlantic production network. These efforts become much more systematic with the introduction of the IBM 360 during the early 1960s. Essential for its success was a concerted effort of IBM R&D laboratories and production facilities in the USA and Europe: the higher-end version 360/40, orientated toward scientific applications, was based on a design developed in IBM's Hursley laboratory in the UK, and the low-end 360/20 was developed in IBM's German labs in Boeblingen. By the mid-1960s, 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 the US facilities, was given a mandate to produce specific products both for the international and the local market (see GLOBALIZATION).

IBM thus was the first computer company to try a full-scale extension of its value chain across national boundaries, albeit still confined to the USA and Europe. This began to change during the 1960s: to reduce costs in manufacturing core memories for the 360 System, IBM began to shift the labour-intensive assembly of these components to low-cost 'offshore' locations in Asia. IBM's

production network 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: 250-1).

IBM's move to Asia did not occur in isolation: it was soon followed by its competitors who also established core array wiring operations in Taiwan and Hong Kong. IBM thus gave rise to a new model of international production for American electronics firms: the re-deployment of labour-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 screwdriver assembly, with very limited local value added and almost no local linkages (Ernst 1983). This originally was an exclusive American affair. Two actors were the main carriers: producers and mass merchandisers of consumer devices, with GE and Sears & Roebuck being the most prominent examples; and medium-sized semiconductor 'merchant' firms that were then still struggling to establish themselves as independent vendors on the open market.

The flagship model in semiconductors

For semiconductors, the pioneer was Motorola which as early as 1967 established production lines in Hong Kong and South Korea. One year later, in 1968, it was followed by National Semiconductor and Texas Instruments which both chose to move first into Singapore. Four years later, both companies established their assembly lines for integrated circuits (IC) 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 could reap by re-importing sub-assemblies from abroad. The

over-riding 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. American semiconductor firms insisted on equity control through the establishment of 100 per cent-owned affiliates, in order to minimize the risk of technology leakage. This practice is in accordance with the theory of foreign direct investment that argues that firms with strong proprietary advantages in technology have a preference for equity control.

Over time, this simple concern with short-term financial savings had to give way to more complex motivations. During the late 1970s, Japanese 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 pre-empt possible attacks by Japanese firms through rapid cost reduction. 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. Equally important, they had to integrate these dispersed supply bases into integrated GPN.

When the US dollar appreciated during the early 1980s, cash-stripped American semiconductor firms moved one step further towards a full-blown flagship model by accepting forms of international production that did not necessarily involve equity control. This practice has given rise to the proliferation of a variety of international contract manufacturing arrangements, ranging from contract assembly to complete 'second sourcing' agreements. Together with the continuous upgrading of existing affiliates, these arrangements have conveyed substantial competitive advantages to American semiconductor firms.

Breakthrough: microprocessors and the PC

A breakthrough in the development of the flagship model came with the emergence of

the microprocessor (MPU) that gave rise to a new kind of computer, the microcomputer (or PC). Both acted as disruptive technologies, as defined by Christensen (1997), reversing the established rules of competition. The MPU failed to have an impact on mainframes and minis because it did not initially offer the computing power and speed that these larger machines could get from multiple logic chips. Existing computer companies thus considered these machines as a small fringe market for hobbyists. The lower production costs of MPUs and their capacity to simplify motherboard design gave rise to an altogether new approach to the design of computer architectures, however, and soon created a thriving demand by new customers who did not need and could not afford the vast computing power of mainframes and minis.

An important turning point came with the Apple II, a relatively open and expandable machine that was designed for volume manufacturing. This compact and attractively designed machine created a highly profitable niche market that IBM, the dominant incumbent, could no longer ignore. On August 12, 1981, the entry of the IBM PC created a new dominant computing platform that has been instrumental in sustaining US leadership. Equally important, but less well known, are the implications for industrial organization. Both the Apple II and the IBM PC were designed around a limited number of standard components. They were designed also as an open box ready for expansion, reconfiguration and continuous upgrading. This architecture gave rise to extensive outsourcing and a rapid geographic dispersion of the value chain. For instance, for the IBM PC, floppy disk drives came from Singapore-based Tandon, power supply from Zenith, motherboards from SCI Systems and printers from Japan's Epson. For the Apple II outsourcing was even more extensive, and final assembly soon shifted to Singapore and Ireland.

Of critical importance however is that, in order to quickly achieve market dominance, IBM decided to outsource the PC operating system (to Microsoft) and the microprocessor design (to Intel). Langlois (1992: 1, 3) highlights one important aspect: the outsourcing of 'external capabilities' that 'reside within a

network of interacting firms'. Of equal importance however is the impact on competitive dynamics and industrial organization. By outsourcing the operating system and the microprocessor, IBM enabled both Microsoft and Intel to capture de facto control over this new architectural standard.

The evolution of the microcomputer accelerated the spread of the emerging flagship model of industrial organization. Consider a stylized GPN (Ernst 1997): it combines a large, multidivisional multinational enterprise (the *flagship*), its subsidiaries, affiliates and joint ventures, its suppliers and subcontractors, its distribution channels and value-added resellers, as well as its R&D alliances and a variety of cooperative agreements, such as standards consortia. A network flagship like IBM or Intel breaks down the value chain into a variety of discrete functions and locates them wherever they can be carried out most effectively, where they improve the firm's access to resources and capabilities, and where they are needed to facilitate the penetration of important growth markets.

The flagship model raises a number of important issues that are highly contested in the literature. For instance, GPN do not necessarily give rise to less hierarchical forms of firm organization (as predicted for instance in Bartlett and Ghoshal, 1989). Network participants differ in their access to and in their position within, such networks, and hence face very different challenges. We use a *taxonomy* of network participants that distinguishes various hierarchical layers that range from flagship companies that dominate such networks, down to a variety of usually smaller, local network participants (Ernst 2001a). The flagship is at the heart of a network: it provides strategic and organizational leadership beyond the resources that, from an accounting perspective, lie directly under its management control.

The strategy of the flagship company thus directly affects the growth, the strategic direction and network position of lower-end participants, like specialized suppliers and subcontractors. The latter, in turn, 'have no reciprocal influence over the flagship strategy' (Rugman and D'Cruz, 2000: 84). The flagship derives its strength from its *control* over critical resources and capabilities, and from its capacity

to *coordinate* transactions between the different network nodes. Both are the sources of its superior capacity for value generation. This taxonomy helps to distinguish the different capacities of these firms to reap potential network benefits, and the institutions and policies required to support weaker network participants.

Increasing vertical specialization is the fundamental driver of this flagship model of industrial organization. Flagships retain in-house activities in which they have a particular strategic advantage; they outsource those in which they do not (Teece 1986). It is important to emphasize the diversity of such outsourcing patterns. Some flagships focus on design, product development and marketing, outsourcing volume manufacturing and related support services (Ernst 2000a). Other flagships outsource as well a variety of high-end, knowledge-intensive support services. This includes for instance trial production (prototyping and ramping-up), tooling and equipment, benchmarking of productivity, testing, process adaptation, product customization and supply chain coordination. It may also include design and product development.

This outsourcing has given rise to a proliferation of specialized suppliers, segmenting the industry into separate, yet closely interacting horizontal layers (Grove 1996). The initial catalyst was the availability of standard components, which allowed for a change in computer design away from closed (IBM mainframe) to open, yet owned, architectural and interface standards for the PC and computer networks (especially the Internet). Tilton (1971) convincingly demonstrates that very early on, the ability to put a 'computer on a chip' opened up new possibilities of industry evolution, with American firms in control of not only the key technology but also the critical system integration capabilities. As a result, new options emerged for outsourcing, transforming an erstwhile vertically integrated industry into closely interacting, globally organized product-specific value chains (e.g. for microprocessors, memories, board assembly, PCs, operating systems, applications software and networking equipment). This process has been accelerated by the introduction of Internet-enabled virtual integration

(Ernst 2001b). Each of these value chains consists of a variety of GPN that compete with each other, but that may also cooperate. The number of such networks and the intensity of competition varies across sectors, reflecting their different stage of development and their idiosyncratic industry structures (Ernst and Ravenhill 1999).

3 Competition puzzles: empirical evidence

The first puzzle: globalization and concentration

In important sectors of the electronics industry, globalization is accompanied by increasing concentration. We first look at peculiar features of globalization and then review data on concentration.

Peculiar features of globalization

Globalization in the electronics industry combines a massive, yet highly concentrated, international dispersion of the value chain, but one with an important organizational innovation – the spread of GPN (see GLOBALIZATION; MULTINATIONAL CORPORATIONS). These networks are a response to the flagship's increasingly pervasive outsourcing requirements and the demanding coordination requirements of geographic dispersion: they integrate the dispersed supply and customer bases of a global network flagship company (e.g. IBM, Cisco, Compaq, NEC, Acer or Samsung). The main purpose is to gain quick access to lower-cost foreign capabilities that are complementary to the flagship's own competencies. The creation of GPN reflects increasing pressures to exploit complementarities that result from the interactive nature of knowledge creation (Antonelli 1998).

Take the outsourcing of volume manufacturing and related support services that enables global brand-name companies to combine cost reduction, product differentiation and time-to-market. A peculiar feature of this new model of industrial organization is that manufacturing is de-coupled from product development, and is dispersed across firm and national boundaries. With an average

annual growth of more than 25 per cent, the so-called *electronics manufacturing services* (EMS) market is one of the fastest growing electronics sectors, expanding twice as quickly as the total electronics industry. The role model for such changes is Soletron, the world's largest EMS provider, with revenues of US\$ 8.4 billion during fiscal year 1999. With a compound annual growth rate of 43 per cent over the past five years, Soletron has now more than 46,000 employees in 41 locations worldwide, with more than 9 million square feet of capacity.

The network flagship outsources not only manufacturing, but also a variety of high-end, knowledge-intensive support services. Most research on the location of knowledge-intensive activities has focused on the role of R&D, but this may be too narrow a focus (for details, see Ernst 2000c). It is necessary to cast the net wider and to analyse the geographic dispersion of cross-functional, knowledge-intensive support services that are intrinsically linked with production. Even if these activities do not involve formal R&D, they may still give rise to considerable learning and innovation. The latter include for instance trial production (prototyping and ramping-up), tooling and equipment, benchmarking of productivity, testing, process adaptation, product customization and supply chain coordination.

The result is that an increasing share of the value-added becomes dispersed across the boundaries of the firm as well as across national borders. Let us look at some indicators. A good proxy of *geographic dispersion* are the growing methodological problems that one encounters when one tries to determine the importance of individual countries and regions in the world electronics market. The difficulties reflect the fact that final products, almost without exception, involve substantial inputs across the value chain that are produced in diverse locations across the globe.

Two measures exist: one is based on company *ownership*, the other on the *country of origin of exports*. Both market-share measures were largely similar, as long as trade was the most important vehicle for international market-share expansion. Both indicators however began to diverge once production dispersed across borders. Take

semiconductors (Reed Electronics Research 1998): there is a huge gap between the US share of world exports (18 per cent) and its market share based on company ownership (32 per cent). This suggests that a very high share of US production is taking place overseas. The gap between ownership-based and export market shares is even higher for Asia (38 per cent by country of origin, versus 19 per cent by ownership), but is the inverse of the US relation, thus suggesting that Asia has attracted the bulk of investments not only from the USA but also from Japan and Europe.

Geographic dispersion however is heavily concentrated in a few *specialized local clusters*. For instance, the *supply chain* of a computer company typically spans different time zones and continents, and integrates a multitude of transactions and local clusters. The degree of dispersion differs across the value chain: it increases the closer one gets to the final product, while dispersion remains concentrated, especially for critical precision components. At one end of the spectrum is final PC assembly that is widely dispersed to major growth markets in the USA, Europe and Asia. Dispersion is still quite extended for standard, commodity-type components ('homogeneous products' in the parlance of industrial economists), but less so than for final assembly. For instance, keyboards, computer mouse devices and power switch supplies are sourced from many different locations, both in Asia, Mexico and the European periphery, with Taiwanese firms playing a major role as supply coordinators. The same is true for lower-end printed circuit boards.

Concentration of dispersion increases the more we move towards more complex, capital-intensive precision components: memory devices and displays are sourced primarily from Japan, Korea, Taiwan and Singapore; and hard disk drives from a Singapore-centred triangle of locations in Southeast Asia. Finally, dispersion becomes most concentrated for high-precision, design-intensive components that pose the most demanding requirements on the mix of capabilities that a firm and its cluster needs to master: microprocessors are sourced from a few globally dispersed affiliates of Intel, two secondary

American suppliers and one recent entrant from Taiwan, Via Technologies.

The *hard disk drive (HDD)* industry provides another example both for the breathtaking speed of geographic dispersion, as well as for its spatial concentration (Ernst 1997). Until the early 1980s, almost all HDD production was concentrated in the USA, with limited additional production facilities in Japan and Europe. Today, only 1 per cent of the final assembly of HDDs has remained in the USA, while Southeast Asia dominates with almost 70 per cent of world production, based on units shipped. 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, Thailand and the Philippines.

Let us take a closer look at firm-level developments. The GPN of Seagate, the current industry leader, provides a good example of *concentrated dispersion*. Today, Seagate operates 22 plants worldwide: 14 of these plants, i.e. 64 per cent of the total, are located in Asia. Asia's share in Seagate's worldwide production capacity, as expressed in square feet, has increased from roughly 35 per cent in 1990 to slightly more than 61 per cent in 1995 – an incredible speed of expansion. Concentrated dispersion is also reflected in the regional breakdown of Seagate's employment: Asia's share increased from around 70 per cent in 1990 to more than 85 per cent in 1995.

The fact that Asia's share in employment is substantially higher than its share in capacity, while the opposite is true for the USA, indicates a clear-cut division of labour: labour-intensive volume manufacturing has been shifted to Asia, while the USA 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 US regions like California and around Minneapolis. 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 leading-edge magneto-resistant (MR) heads. This is in line with similar specialization patterns displayed by other leading HDD producers.

We need to add a further aspect: an extreme spatial concentration *within* East Asia, which now handles most of Seagate's volume manufacturing. Slightly more than 92 per cent of Seagate's capacity in Asia is concentrated in three locations: in Bangkok (almost 32 per cent), Penang (more than 30 per cent) and Singapore (a bit less than 30 per cent). And almost 50 per cent (26,000 out of 55,000) of Seagate's Asian employment is concentrated in its plant in the outskirts of Bangkok. These data indicate that Bangkok is the centre for low-labour cost volume manufacturing. Next comes Singapore with more than 27 per cent (15,000), substantially more than Malaysia's 16 per cent (9000 people). For both Singapore and Malaysia, the low ratio of employment relative to its share in Seagate's production capacity indicates that 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 labour 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.

Concentration

Concentration in the electronics industry is high and often keeps rising, despite a heavy exposure to globalization. It is well known that, in terms of market shares, both computer operating systems and microprocessors are each overwhelmingly dominated by one company, Microsoft and Intel respectively. Concentration is also substantial for high precision key components that are critical for architectural design and performance features, such as DRAM, advanced displays and HDD. Let us look at relevant data for the latter industry.

Market share data indicate a very high degree of concentration: five companies account for roughly 85 per cent of worldwide non-captive HDD sales. Concentration ratios are also very high for key components. Take head assembly: the 10 largest head manufacturers account for 93 per cent of the market by volume, with the largest six firms alone controlling 78 per cent. One indicator of increasing concentration is the rapid decline in the number of worldwide drive manufacturers: the total shrank from 59 in 1990 to 24 in 1995, with most of the decline taking place after 1993. In 1995, nine companies went out of business, and only three companies entered the fray, all of them in niche markets. During the same year, Seagate, the current market leader, acquired Conner Peripherals, the company that, in 1992, was the world market leader. Furthermore, two heavyweights, Hewlett Packard and DEC, left the HDD industry altogether during 1996.

High and increasing concentration can also be found for other key components. Take DRAM, the largest segment of the semiconductor market. The DRAM market is now even more concentrated than the world oil industry was at the peak of the rule of the infamous *seven sisters*: six business groups control almost 88 per cent of the world market (up from 67.1 per cent in 1998). Of even more importance, the four top firms now control more than two-thirds of the DRAM market (up from 50.8 per cent in 1998).

We find increasing concentration even in the PC industry, an industry which only a decade ago was hailed by neo-liberals as a holy grail of free competition (Gilder 1988). The top four market players – Compaq, Dell, IBM and Hewlett Packard – have consistently expanded their combined global market share from less than 27 per cent in 1996 to 37.3 per cent in 1999. During this period, the four industry leaders have captured almost 70 per cent of PC unit growth worldwide. Concentration is substantially higher in the all-important US market, where the top four PC makers now hold about 68 per cent. Concentration is also very high and rapidly increasing for *notebooks*, an industry that used to be crowded with many competitors: the total market share of the ten largest firms was 64.2 per cent in

1995, rose to 68.3 per cent in 1996 and stands now around 75 per cent.

Similar trends can be observed in the electronics manufacturing services industry. While only a few years ago, many of these firms were of humble size, concentration is now increasing at a breathtaking pace, based on a wave of M&A (mergers and acquisitions). During 1999, more than 100 mergers occurred in this sector, up from 50 in 1997. If this trend continues, this industry will be soon dominated by handful of large, integrated manufacturing service providers, each with revenues of at least \$10 billion. Solectron's recent purchase of Nortel's worldwide manufacturing operations documents the speed of these transformations. In one stroke, this acquisition expanded Solectron's global production capacity by 1.2m square feet, an increase of capacity of roughly 20 per cent.

Finally, concentration keeps rising rapidly even in newly emerging sectors such as Internet software and networking equipment, despite the fact that there are new entrants by the droves. In the market for ISPs (Internet service providers), huge global telecommunications companies, together with the market leader AOL, have aggressively increased their market share through a wave of M&A. Equally important is an increase in concentration in the rapidly growing ASP (application service providers) market. As that market becomes more profitable, large global players have become the dominant players. Included among these dominant ASPs are computer and software companies (Oracle, Sun Microsystems, IBM, Intel, and Hewlett Packard), telecommunications companies (AT&T and Qwest), consulting companies (KPMG) and financial firms (e.g. Merrill Lynch).

In the market for networking equipment, Cisco's original leadership position has been eroded by multiple attacks. Telecommunications equipment vendors, especially Nortel Networks and Lucent Technologies, have entered the fray. Cisco has responded in kind by entering the market for telecommunications equipment. In addition, computer companies, such as IBM, Compaq and Hewlett Packard are also now producing some networking equipment (e.g. switches, hubs and adaptor

cards), although they are not yet as major players.

As a result, a small group of North American firms dominates networking equipment, with very limited competition from suppliers in Japan and Europe. Competition between the top firms (Nortel, Cisco, 3Com and Lucent) is very intense and has fuelled various rounds of mega-M&A, hence it is possible to talk about an unstable global oligopoly. As in other sectors of the electronics industry, increasing concentration goes hand in hand with substantial volatility of market positions. What sets the networking equipment industry apart, is the extremely rapid pace of technological change which is concentrated in two areas: increased network bandwidth, and transmission speed to alleviate congestion. The result is an industry in turmoil where incumbents as well as a handful of new entrants fiercely compete for market positions. Note however that the speed of change has slowed down since the beginning of the US recession in late 2000.

The second puzzle: concentration and volatility

This brings us to a second puzzle that is equally surprising: even when concentration is very high, the electronics industry fails to act like a stable global oligopoly (as predicted, for instance, by Borrus 1989 and Ferguson and Morris 1993). Take again the example of the HDD industry.

According to Blair (1972), oligopoly begins when the four largest firms hold more than 25 per cent of overall sales. Between 25 and 50 per cent, this oligopoly is loose and unstable, but above 50 per cent, it becomes firm and clearly established. With five companies holding roughly 85 per cent of the global market, we would have to conclude that the HDD industry is controlled by a very tight oligopoly. This conclusion however does not square well with the fact that the HDD industry is a continuous prey to cut-throat price wars and highly volatile market positions. Despite a number of major shake-outs, the industry remains highly unstable: market positions keep changing at short notice, and not even market leaders can count on a guaranteed survival.

For instance, Conner Peripherals was the market leader in 1992, with 24 per cent. Yet, one year later, Quantum had leapfrogged both Conner and Seagate to become No. 1. Conner Peripherals in turn fell back to the third position, and saw its market share erode to 16 per cent in 1994. In 1995, the industry experienced yet another round of swapping market leadership positions, with Seagate now recapturing 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 had been content 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 Korean Hyundai group which, in 1995, acquired 100 per cent ownership of Maxtor, one of the industry's pioneers. Since then, Maxtor has experienced a highly successful comeback, and is now considered to be one of the industry leaders in technology, quality and speed of response.

Major changes are currently again transforming this industry, with the result of a drastic repositioning of market shares and a redefinition of the rules of competition. The result is a pervasive profit squeeze and a fall in asset prices: HDD firms that are negatively affected by these developments are forced into a defensive chain reaction. The most prominent example is the erosion of Seagate's market leadership position since the fall of 1997. This decline in market share reflects an accelerated pace of market volatility. IBM, the sleeping giant, has finally woken up and is now aggressively competing for market share, based on its leadership in the technology of key components like MR heads. Japanese competitors (especially Fujitsu) have aggressively developed a highly productive low-cost production base in the Philippines. As Fujitsu is much larger than the current industry leader Seagate, it has the resources necessary for this

aggressive frontal attack. Other new contenders include Toshiba, Hitachi, NEC and Samsung, all of whom have invested in an aggressive market share expansion strategy.

4 Possible explanations

The empirical evidence on the competitive dynamics of the electronics industry runs counter to much of the established literature. What are possible explanations?

Brief review of the literature

For quite some time, the *structure-conduct-performance* (SCP) paradigm dominated the debate on competition. In this view market structure, as captured by concentration of sellers, is the primary determinant of both conduct and performance. One of the classic sources (Bain 1958) 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.

The SCP paradigm has lost much of its earlier grip on the debate. The theory of 'contested markets' argues that even highly concentrated industries will be forced to price competitively, provided they face the 'discipline of potential hit-and run entry' (Baumol *et al.* 1982). The crux of this analysis is the existence of 'sunk costs': the higher they are, the less likely is the market to be contestable. The electronics industry, with its high 'sunk costs' due to R&D, thus should be less contestable.

Globalization however 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 overseas markets. This observation has provoked some counter-arguments that come to very different conclusions. As globalization leads to market expansion, sunk costs and scale economies increase apace, further increasing concentration. The latter 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 (Sutton 1991).

Such, in fact, has been the case for the HDD industry: prices have been falling about 30 per cent per year for more than a decade, fostering increasing concentration. Note however, once concentration reaches a certain level, there may well be a reversal of pricing trends. For instance, the drastic increase in concentration in the PC industry reported earlier has led to some price increases during the first quarter of 2000, after a long period of dramatic price falls (Ernst 2000c).

An alternative approach

In short, the literature allows for conflicting explanations. A major weakness of the 'sunk costs' perspective is its failure to address the critical role of innovation. This is a general weakness of 'industrial organization' (IO) theory. According to Richard Lipsey, 'most I.O. theory is about competition in prices, quantities (short run) and capacity (long run) when in fact the competition that really matters, and that drives firms' successes and failures, is competition in technologies (very long run). ... (This) has led to increasingly fierce competition among oligopolistic firms even when there are only a few in any one industry' (letter to the author, October 10, 2000).

An alternative approach can be based on a recent paper by George B. Richardson (Richardson 1996) that argues that competition for *given* products is only 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: 4). Yet, competition in reality centres on development and innovation. Such technological competition is especially true in the electronics industry. Christensen's excellent book on 'disruptive technologies' (1997) provides a second equally important source for an alternative explanation of the puzzling competitive dynamics of the electronics industry.

Competitive dynamics and innovation

Fundamental changes in the electronics industry have transformed its competitive dynamics: a high and growing knowledge intensity, combined with the rapid pace of change in technologies and markets has given

rise to an extensive globalization. Let us focus on the dual impact of ICT: it both increases the need for and creates new opportunities for globalization. This argument is based on two propositions. First, the cost and risk of developing ICT has been a primary cause for market globalization: international markets are required to amortize fully the enormous R&D expenses associated with rapidly evolving process and product technologies (Kobrin 1997:149). Of equal importance are the huge expenses for ICT-based organizational innovations (Ernst and O'Connor 1992: chap. 1). As the extent of a company's R&D effort is determined by the nature of its technology and competition rather than its size, this rapid growth of R&D spending requires a corresponding expansion of sales, if profitability is to be maintained. No national market, not even the US market, is large enough to amortize such huge expenses.

A second proposition explains why international production rather than exports have become the main vehicle for international market share expansion. Partly this change reflects the pace of liberalization: while originally international production was driven by the need to overcome protective barriers ('tariff-hopping'), over time liberalization has become a major pull factor. Of critical importance however has been the enabling role played by ICT: it has substantially increased the mobility, i.e. dispersion, of firm-specific resources and capabilities across national boundaries; it also provides greater scope for cross-border linkages, i.e. integration. Developments in ICT have substantially reduced the friction of time and space, both with regard to markets and production: a firm can now serve distant markets equally well as local producers; it can also now disperse its value chain across national borders, in order to select the most cost-effective location.

In addition, ICT and related organizational innovations provide effective mechanisms for the international diffusion of knowledge that is required to establish, operate and continuously upgrade spatially dispersed locations (Naughton 2000). It is now possible to construct an infrastructure that can link together and coordinate economic transactions at distant locations. This possibility has important

implications for organizational choices and locational strategies of firms. In essence, ICT fosters the development of leaner, meaner and more agile production systems that cut across firm boundaries and national borders. The underlying vision is that of a network of firms that is able to respond quickly to changing circumstances, even if much of its value chain has been dispersed.

The growth of these networks has drastically changed the dynamics of competition. Again, we reduce the complexity of these changes and concentrate on the most important impact: the emergence of a 'winnertakes-all' competition model: '... the player with the largest share in a horizontal layer is the one who wins' (Grove 1996: 48). This outcome implies that economies of scale and scope are of critical importance for competitive success, especially for key components like microprocessors and operating systems. Equally important however is a capacity to control open-but-owned architectural and interface standards (Ernst and O'Connor 1992; Borras *et al.* 2000).

A third important feature of the new competition model is found in the increasingly demanding requirements for time management and coordination. The rapid pace of change of ICT has drastically shortened the product life-cycle: only those companies thrive that succeed in bringing new products to the relevant markets ahead of their competitors. Of critical importance is that the firm can build *specialized* capabilities quicker and at less cost than its competitors (Kogut and Zander 1993). The increasing segmentation of the electronics industry furthermore requires a capacity to coordinate dense interactions between independent market segments that feed into the final system products.

Fourth, all of this reorganization needs to be combined with aggressive price cutting across the board. PC prices have fallen by 20 per cent or more over the last two years, giving rise to razor-thin profit margins – 1.5 per cent margins are the current average for standard PCs. Deflationary pricing pressures are driven by an apparently unstoppable move towards low-end products, such as cheap PCs and mobile devices, thus intensifying the industry's profit squeeze.

Finally, an important additional constraint is that pricing strategies at the level of systems brand-name companies (e.g. Compaq) or sub-assembly producers (e.g. Seagate) are determined by the frequently abrupt price changes implemented by the lead suppliers of key components (e.g. Intel). Even minor increases in the price of a microprocessor or a display can produce substantial losses. On the other hand, sudden price declines for such components can also have very negative consequences, if the company has overstocked these components. In 1999 for instance PC components declined in value at 1 per cent or more per month, giving rise to very high inventory costs.

Disruptive technologies

'Disruptive technologies' underperform relative to established products in mainstream markets today, but may be fully performance-competitive in the same market tomorrow. Disruptive technologies differ from 'sustaining technologies' which improve the performance of *established* products that mainstream customers in mainstream markets have traditionally valued. Disruptive technologies bring to a market very different products: they have features that, initially only a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller and, frequently, more convenient to use.

Disruptive technologies can help to explain why high concentration co-exists with high market volatility. The explanation derives from the puzzling fact that incumbents apparently face more severe barriers to invest in disruptive technologies than new entrants. This is so for four reasons: (1) these technologies are simpler and cheaper, and thus promise lower margins, not greater profits: 'It is very difficult for a company whose cost structure is tailored to compete in high-end markets to be profitable in low-end markets as well' (Christensen 1997: xx); (2) disruptive technologies are first commercialized in emerging and insignificant markets that large companies have great difficulties in addressing; (3) the incumbents' most profitable customers generally do not want, and initially cannot

use, products based on disruptive technologies; and (4) a break of routine requires a different organizational design from sustaining technologies that can rely on customary routines.

In short, disruptive technologies provide a constant threat to the excessive product differentiation pursued by incumbents to reap the benefits of premium pricing. New entrants however face relatively low entry barriers for such technologies, compared to the entry barriers that characterize sustaining technologies.

Stylized model of competitive dynamics

That explosive mixture of conflicting requirements explains the co-existence of concentration and market volatility in the electronics industry. More specifically, we distinguish sources of concentration that may stabilize markets from sources of market volatility. Among the first, we highlight the role of 'scale economies' in manufacturing, and the heavy 'sunk cost' of rapid innovation and of developing complex capabilities. The latter are of increasing importance, reflecting a growing knowledge intensity.

As for the sources of market volatility, we consider: 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 disruptive changes in demand and technology. A sectoral approach is of the essence: we need to identify basic characteristics of an industry in order to understand what forces shape competitive dynamics. To illustrate this stylized model of competitive dynamics, we focus on data from the HDD industry.

Sources of concentration

Scale economies in manufacturing

Rising *minimum economies of scale* are an important driver of concentration in the HDD industry. In final assembly, scale economies are largely attributable to costly facility 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 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 have grown very rapidly over time. For instance, in 1989 an annual production capacity of between 900,000 and 1 million units was regarded as economic scale (Ernst and O'Connor 1992: 194). Since then, a dramatic increase has occurred in minimum scale. Take the 1996 capacity figures reported by Maxtor-Hyundai, which is in line with other comparable projects. 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.

Sunk costs of innovation and capability development

A second important driver of concentration is the very high sunk costs of rapid innovation and of developing complex capabilities. The HDD industry is 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 per cent a year. The speed of access to data is also rapidly increasing. 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.

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 technology 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 integrated circuits. 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 architectural design and software capabilities have been of crucial importance as instruments for product development and differentiation strategies. In short, generating a constant stream of new products and key components requires huge sunk costs. The latter deter potential new entrants; they also force incumbents to increase their market share.

Sources of market volatility

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. On average, a new product generation is introduced every nine months, and for some products the cycle can be as short as six months, almost as short as for fashion-intensive garments. These short cycles lead 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 (Ernst 1983). 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 first supplier. 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 very quick responses to changes in markets and technology.

Short product cycles thus are an important source of market volatility. Even with all the progress made in the flexibility of supply chain management, it is very difficult to avoid periodic mismatches between supply and demand. Each time the supply of HDDs overshoots demand, price wars break out. The result is that HDD producers must combine cost leadership with technology leadership and speed-to-market, a combination that can threaten even apparently unbeatable market leaders.

A complex supply chain

A complex supply chain can be a second important source of market volatility. Logistical requirements are very demanding in the HDD industry: a wide variety of high-precision components and sub-assemblies needs to be procured from a variety of suppliers 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. These supply shortages lead 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.

That vulnerability keeps rising further with an increasing reliance on outsourcing. The case of Maxtor illustrates how deadly this vulnerability can be. Maxtor's main weakness has been a lack of strong in-house circuit

design expertise, forcing the company to outsource key circuitry. In 1995, at the peak of a periodic shortage of DRAM and other chips, supply disruptions led to a dramatic fall in Maxtor's market share and its acquisition by Hyundai.

Disruptive changes in demand and technology

Finally, disruptive changes in demand due to competing technologies are powerful causes of market volatility. As suppliers of an intermediate input to the computer industry, HDD firms compete for design-ins by computer companies. The latter 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 breakthrough 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 EEPROM more durability for portable applications. There is a widespread consensus that, so far, none of these competing technologies poses a serious threat to HDD.

Of critical importance however are breakthrough innovations in architectural design and in component technology that have periodically caused quite serious turmoil in the HDD industry. For instance, new optical data storage technologies are currently emerging that may have trajectory-disrupting effects. Such a technological change privileges newcomers to the HDD market like Sony and Philips which have strong positions in optical technologies; it creates a serious problem for the current market leader Seagate which is weak in these technologies.

No HDD company can afford to neglect such demand volatility. Much depends on the kind of customers to which the HDD company is linked. If these customers are established market leaders intent on sustaining the status quo, there is a danger that the HDD manufacturer may be locked into a trap of obsolete architectural designs. If however the HDD company succeeds in broadening its customer base to include computer companies that are content 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.

This dilemma implies that a firm's competitive position depends as much on the nature of demand as on the constraints resulting from available technologies (Christensen 1997). 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. Take the example of IBM's storage division, the creator of the HDD industry. Although it was the first to develop most of the key components and although it was unrivalled in its accumulated capacity for architectural design, IBM was arguably the last firm in the industry to incorporate leading-edge components across the spectrum of its product line. Reflecting its high level of its organizational costs, IBM was eager to reap premium prices: it thus normally used sophisticated componentry only in high-end drives. This practice opened the door for new entrants like Seagate and others that were able to start with much lower organizational costs and hence could afford to develop new markets for smaller-size disk drives for desktop computers that generated much lower unit profits, but quickly grew into huge mass markets.

Strong product and market development capabilities thus are of critical importance for sustaining industrial leadership positions. The

conclusion that matters for our purposes is that no HDD company can afford to neglect the possibility of trajectory-disrupting innovations. This fact of life obviously adds quite substantially to the complexity of the competitive challenges in this industry, broadening the scope for market volatility.

5 Key questions for ongoing research

This brief review of research on how competitive dynamics reshapes industrial organization in the electronics industry clearly indicates that we can no longer take for granted some of the earlier credos of competition theory. We need to take a fresh look at the determinants of market structure and firm behaviour. 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: 9).

Due to the rapid pace of change in ICT, radical transformations occur quite frequently in the electronics industry. The following quote from the director of the Rank Xerox Cambridge Laboratory illustrates the challenge:

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).

(Anderson 1997: 5)

This hectic pace of change arguably is the most important economic characteristic of the electronics industry.

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 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: 7)

We still know very little about this important topic. Attempts to move a bit further ahead into this uncharted territory need to address, both theoretically and empirically, a number of important questions. For instance, to what degree can one generalize the above findings, i.e. how does the electronics industry differ from other knowledge-intensive manufacturing and service industries? Second, 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 that are also less time-sensitive and prone to disruptive changes in demand?

Third, to what degree have recent developments in ICT, and especially the Internet, further increased the already high knowledge-intensity and exposure to globalization, hence posing new competitive challenges for the electronics industry? Fourth, what changes have occurred in the locus of economies of scale and scope? And how has the increasing cost and risk of technology development affected entry barriers? Fifth, under what conditions can GPNs in these industries enhance the diffusion of knowledge across firm boundaries and national borders, and hence create new entry possibilities for smaller firms and economies? Sixth, how valid are claims that the electronics industry, and especially its incarnation in the USA, has given rise to a New Economy growth model that allows for higher

rates of non-inflationary growth? What are its opportunity and welfare costs, and its impacts on a society's long-term innovation potential? What explains the global recession of the electronics industry since late 2000? And, finally, 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 industrial dynamics 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 competitive success.

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See also: COOPERATION AND COMPETITION; CORPORATE CONTROL; DEVELOPMENT AND DIFFUSION OF TECHNOLOGY; DYNAMIC CAPABILITIES; EAST ASIAN ECONOMIES; ECONOMIC GROWTH AND CONVERGENCE; ECONOMIC INTEGRATION, INTERNATIONAL; ECONOMY OF JAPAN; ELECTRONICS INDUSTRY; EVOLUTIONARY THEORIES OF THE FIRM; GLOBALIZATION; GROWTH OF THE FIRM AND NETWORKING; GROWTH THEORY; INDUSTRIAL DYNAMICS; MULTINATIONAL CORPORATIONS; SMALL AND MEDIUM SIZED ENTERPRISES; TELECOMMUNICATIONS INDUSTRY