

**INDUSTRIAL DYNAMICS AND THE EVOLUTION  
OF FIRMS= AND NATIONS= COMPETITIVE CAPABILITIES  
IN THE WORLD COMPUTER INDUSTRY**

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April 1997

We would like to thank Salvatore Torrasi for sharing with us his knowledge about the U.K. industry; Simona Heidemperger, Lu-Leng Chua, and Victoria Danilchouk for much assistance, and David Mowery, Richard Nelson, Richard Rosenbloom, Giovanni Dosi, Martin Fransman, Steve Klepper, Sidney Winter, Peter Murmann and the participants of the CCC project for useful comments and suggestions. We thank the Italian CNR and the Sloan Foundation for research support.

## 1. The major issues

The evolution of the computer industry over the long term illustrates many of the broad themes addressed by this book. In particular, it highlights the coevolution of technology, market structure, and institutions, and addresses the sources of international competitive advantage. Since its inception in the early 1950s, the computer industry has been characterized by rapid and sustained technical change, continuous product innovation punctuated by a few major breakthroughs, creation of new uses for computers and new markets and coexistence between established actors and new entrepreneurial firms. And since the beginning of the industry, one country -- the United States -- has been the world technological and competitive leader.

From these remarks drawn from the history of the world computer industry, some questions emerge. A first set of questions refer to the *relationship between radical change and competition among incumbents and new firms*. How is it that old and new firms coexisted during the history of the computer industry? Is there a link between radical innovations opening up new markets and the competition between old and new actors? A second set of questions relate to the *specific relationship between technological change, market structure, and institutions* during the history of the industry. Was there a unique type of coevolutionary process during the whole history of the industry? Or was there more than one coevolutionary process? In either case, why? A final set of questions relate to the *persistence of international technological and competitive advantages of one country* during the whole history of the industry. Why was the United States, and not other countries, able to profit from the opportunities to become world technological and competitive leader? How was the United States able to persist in that role? This chapter is going to try to answer these questions using a historical and analytical perspective.

A first look at the major features of the computer industry identifies some aspects that are going to be relevant for the analysis presented in this paper. First, computer hardware has advanced very rapidly in price/performance measures, fueled by rapid advances in the underlying electronic components as well as in computers themselves.<sup>1</sup> A wide variety of hardware categories has emerged: large and powerful computers such as mainframes, intermediate classes such as minicomputers and workstations, and classes with less expensive products such as personal

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<sup>1</sup> For an extensive review of measurement studies of computer price/performance ratios, including extensive discussion of alternative definitions of performance, see Gordon (1989). On any definition of price/performance, 20-25% improvements have been sustained over four decades. For a key class of electronic components, semiconductors, see the chapter in this volume by Langlois and Steinmueller, and Malerba (1985).

computers. Technical progress has made the largest computers much more powerful, the smallest more affordable, and increased choice and variety in between. Computer hardware was once supplied by a few pioneering firms; now there are hundreds of suppliers. The impact of performance increases and price decreases, together with dramatic improvements in complementary technologies such as software, storage devices, and telecommunications, and with considerable innovations and learning-by-using by customers, has been to build a multi billion dollar worldwide industry.

Second, widespread adoption of computers in business and among consumers has contributed to this ongoing growth. Three very different kinds of *demand* are important here. First are the *buyers of large computers for business data processing*. These demanders are professionalized computer specialists in large organizations.<sup>2</sup> These sites have absorbed dramatic increases in computer power.

Thus, while mainframe computing sites number only in the tens of thousands, their total market size is very large. A second kind of demand is that for *individual productivity applications* on PCs. This is a newer body of applications, first reaching measurable commercial importance about fifteen years ago. Most use depends on mass-market software, such as word processing or spreadsheet programs.<sup>3</sup>

This market has seen much growth in two ways: by replacement and upgrading, and by diffusion, as more and more (especially) white-collar workers have seen their work at least partially computerized.

In this segment, individual customers tend to buy hardware and software from a wide variety of vendors in arms-length, market relationships. Unit sales of successful products run to the millions.

Individual demanders are small, however, so that through the late 1980s the market sizes for the first two types of computing were roughly equal. The third demand is composed by *scientific, engineering, and other technical computation*. Served by supercomputers, by minicomputers and later by workstations, factories, laboratories, and design centers do a tremendous volume of arithmetic.<sup>4</sup> In total, technical computing market size is roughly as large as each of the two kinds of commercial computing described above.

This variety in demand has permitted the emergence of *different suppliers and markets*. Market segmentation has meant, for much of the history of the industry, that mainframes, minicomputers, and PCs have served distinct kinds of demands. More importantly, demand variety has permitted the emergence of new, entrepreneurial firms in parallel to established ones. Even as the oldest segment,

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<sup>2</sup> They have close bilateral working relationships with the most important vendors. The computer business systems are complex pieces of computer software, entailing an equally complex innovation process. In the industrialized countries, most of the sites doing this kind of computing have been in operation for decades. A process of learning by using, plus ever cheaper large computers, has led to considerable replacement and upgrading of facilities

<sup>3</sup> See Mowery in this volume for a detailed treatment of software.

<sup>4</sup> Here the users are technically sophisticated, and the applications have crisp technical goals. Buyer-seller relationships are more like arms-length markets than close bilateral links.

mainframe computers, was consolidating around a dominant firm (IBM) and dominant design in the early 1960s, other firms (notably DEC) were creating the minicomputer segment. Later, other segments such as personal computers, workstations, and superminicomputers would offer yet more entry opportunities. This observation leads us to our first analytical distinction. We first treat the industry dynamic surrounding the creation and persistence of IBM's leadership in mainframe computing from the late 1940s to the late 1980s. We treat the industry dynamic which created new markets by new entry separately, as its coevolutionary processes are fundamentally different.

*Industry Dynamic 1: Creation and Persistence of IBM's Leadership in Mainframes  
(late 1940s - late 1980s)*

For our purposes, *mainframe computers* are systems used for large departmental or company-wide applications.<sup>5</sup> We shall cover mainframes from the very early period, the time before a clear definition of a business computer or a computer company emerged, up to the late 1980s. IBM emerged from an early competitive struggle to dominate supply, in the process determining the technologies needed for computing, the marketing capabilities needed to make computers commercially useful, and the management structures that could link technology and its use. Competitors, customers, and even national governments have defined their computer strategies in relationship to IBM. IBM was the manager of both the cumulative and the disruptive/radical parts of technical change. Customers= learning by using and IBM engineers= learning by doing were focused on the same IBM computer architectures. When an established technology aged, IBM was not only its owner but also the innovator of the new.

*Industry Dynamic 2: Creation of New Market Segments and Entry (late 1950s-late 1980s).*

The second industry dynamic saw the founding and evolution of new computer segments and markets. *Minicomputers* are machines intended for scientific and engineering use; when used in commerce they fall into support roles such as communications controllers. *Microcomputers* (personal computers) are low price, small systems for individual applications, both in business sites and at home. *Workstations* are used by individual engineers in graphics and computation-intensive applications such as design. In this dynamic, a series of new markets were opened up by entrepreneurial startup firms. While there was some sharing of fundamental technical advance, each new segment's founding was characterized by considerable innovation and entry. As a result, the

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<sup>5</sup> The boundaries of the mainframe segment are not clear. Commercial minicomputers eventually became much like mainframes. We do not treat the development of the commercial minicomputer segment. For our (international comparison) purposes, the commercial minicomputer segment<sup>4</sup> can be thought of as an extension of the mainframe segment.

technologies, as engineers use that term, of different segments were distinct. Those new segment foundations that led to viable markets brought computing to new kinds of demanders. Successful firms tended to be specialized. Buyers were departments of firms or individuals. Each of these segments saw some maturation toward a dominant computer design, and toward a dominant model of the appropriate supplying firm for the segment.

*Industry Dynamic 3: Entry into the mainframe market by networks of small computers and rent-destroying challenge to IBM's leadership (1990s)*

The 1990s have seen a third industry dynamic. Reversing the longstanding trends of Industry Dynamics 1 and 2, this era saw competitive convergence of computers of all sizes in the 1990s. Existing types of small computers were networked together and offered to IBM's traditional customers.<sup>6</sup> The new technical and competitive importance of networks of small computers has eroded the earlier market segmentation between mainframes, mini, and micro. After a decade of stable segmentation, the distinct kinds of computers that had evolved in Industry Dynamics 1 and 2 came into direct competition with one another. A client/server platform uses computer networking to link together user-friendly clients (such as PCs) with powerful servers (bigger PCs, workstations, minicomputers or mainframes). The computer network consists of clients and servers, quite likely sold by different hardware and software companies, and networking infrastructure, likely sold by yet others. The networked computer became the platform on which large applications can be built. The buyers in this area are a complex mix of individuals, departments, and enterprises. As we write, neither the dominant design for a network of computers nor for a computer company in this environment is clear.

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<sup>6</sup> See Bresnahan and Greenstein (1995) for an explanation of this reversal.

The three industry dynamics have been characterized by *coevolution* of firms= capabilities, strategies and organizations, technologies, and market structures, and (often) by a changing relationship between the industry, public policy, and national institutions. As we will show more in detail later in this paper, at the initial stage of each industry dynamic the coevolutionary process was caused by the introduction of a new technology developed by an inventor or a firm. The new technology spurred entry of new or established firms which added modifications and changes to the original technology. In our three industry dynamics, the new technology addressed a new demand and new types of users, or old types of users in a radically new way. This created specific types of user-producer relationships, which led firms to develop new competencies and organizations. Over time, firms developed appropriate competencies, strategies, and organizations more suitable for the new technology. These firms made new innovations and fostered the rate of technical change in specific directions. Relatedly, public policy and institutions were relevant at various stages of the evolution of the computer industry: some policies and institutions remained unchanged over time, while others evolved in tune with the specific industry dynamic and changed in various degrees and forms in different countries. As we will show later on, however, this coevolution of technology, firms= capabilities, strategies and organizations, industry structure and public policy and institutions proceeded *differently in each industry dynamic*, with congruence between firms= strategies, industry characteristics, and countries= performance.<sup>7</sup>

A first look at the three industry dynamics shows that the *United States* has been *persistently the innovative and commercial world leader* in the computer industry. In Industry Dynamic 1, IBM emerged as the world leader. IBM, and therefore the U.S., persisted in its leadership despite competitive attacks from individual companies, strategic alliances, and even whole national computer industries such as Japan's. In Industry Dynamic 2, new successful American firms entered emerging market segments while IBM continued to maintain its dominance in mainframes. Finally, in Industry Dynamic 3, the challenge to IBM's leadership came mainly from American firms, as a result of the convergence between mainframes and networks of smaller computers. We examine the different reasons behind American success in each of the three periods.

The paper is organized in the following way. In sections 2 to 6 we discuss industry coevolution and the international competitive advantages in a comparative way (the United States, Europe, and

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<sup>7</sup> A segment not treated is workstations. The history of this segment has many of the same elements of the microcomputer history.

Japan). In section 2 we analyze the birth of the new industry during the late 1940s and early 1950s and the emergence and persistence of IBM world leadership in mainframes for more than four decades. In sections 3, 4, and 5, we discuss the growth of new market segments (mini and micro computers respectively) and the entry, success and growth of new American actors who became world leaders. In section 6 we examine the challenge to IBM domination in mainframes coming from computer networks and other existing American firms. Finally, in section 7 we draw some general conclusions from the analysis.

## **2. The birth of the new industry: major similarities in the United States and Europe**

The early period of many pioneering efforts leading to the emergence of a mainframe computer industry was characterized by extreme similarity in the initial conditions and types of entrants between the United States and Europe, with Japan lagging behind. The scientific capabilities of the universities in the United States and Europe and the structure and capabilities of the connected industries--office equipment and the electrical-electronic industry--were very similar.

### **2.1 The major role played by universities around the world in the pre-commercial period**

In the very early years of the industry (1940s) universities in both the United States and Europe were active at the scientific and prototype levels. In the United States, scientists in universities worked in cooperation with the government which acted both as a source of funds and as a major potential consumer of technology, notably in the military and the Census Bureau. In addition, a few private firms also funded basic research in computers (IBM, for example, supported the development of the Mark I computer of Aiken at Harvard in 1944).

The scientific commitment by various American and European universities to develop digital electromechanical computers led to the development of several machines during the 1940s. In the United States, for example, ENIAC, the first digital electromechanical computer, was developed by Eckert and Mauchly in 1946 with the support of the Army at the University of Pennsylvania. The military also sponsored Project Whirlwind at MIT leading to the development of magnetic core memory.

European research in computers was at the world scientific frontier during the 1940s. In the UK, after the development of the Colossus (1945) (a computer similar to ENIAC) and ACE (1945), Manchester and Cambridge Universities moved to the forefront of research. Manchester University developed the Mark I (1948) (the first computer to use a magnetic drum memory) and Manchester

University's Digital Machine (MADM) (1949), and Cambridge University developed the EDSAC (1949). In Germany, Konrad Zuse, of Berlin University, was very active in this field. During the 1930s, he built a series of electromechanical calculators (Z-1, Z-2, Z-3, and Z-4). The Z-3 was the first one fully operational, while Z-4 was installed in a German V-2 rocket plant and at the end of the second world war was leased to the Swiss Polytechnic Institute.

In the United States, the origin of the commercial computer industry came with the move of the two inventors of ENIAC from university into the business world. In 1946 Eckert and Mauchly established their own firm, the Eckert-Mauchly Corporation, to develop general purpose commercial computers for scientific as well as for business accounting uses. The Eckert Mauchly enterprise failed, however, because external finance (particularly venture capital) was limited.<sup>8</sup>

Later on, in the 1950s, the role of universities expanded to include participation in the development of technologies that would be used in government projects or embedded in existing firms' products.<sup>9</sup>

## **2.2 Three types of entrants around the world**

Mainframes were the first commercial products developed and sold in the computer industry during the 1950s. They made extensive use of magnetic drum memories and, later on, of transistors. Early computers' functionality focused on scientific uses, then expanded to business uses such as accounting. The first mainframe producers maintained links with universities and continued to have government (military) support. They also opened up extensive linkages with business firms who became major users of computers.

The success of IBM's model of a computer company, characterized by a Chandlerian three pronged investment in technology, marketing, and management, is now very familiar. We should remember, however, that this model was not obvious to market participants in the early period.

Three distinct types of entrants entered the industry: office equipment producers, electronics firms, and new firms. Among office equipment firms, the most prominent were IBM, Remington-Rand (later Sperry Rand), Burroughs, NCR (which later on bought CRC), Olivetti, Bull, and BTM (an IBM distribution partner). Among electronics firms, General Electric, Honeywell, RCA, Siemens, Standard Elektrik Lorenz, Telefunken, GEC, and Ferranti. New firms were less important competitively but included CDC, SDS, ERA, CRC, Eckert-Mauchly (sold later to Remington Rand),

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<sup>8</sup> Some (albeit insignificant) financial support came from firms such as Prudential, Nielson and Northrop Aircraft. These financial sources were not sufficient and in the 1950 the Eckert-Mauchly Corporation was acquired by Remington Rand.

<sup>9</sup> See OECD (1966) and Flamm (1988) for a description of the American and European efforts.



Nixdorf, and Zuse. All three types of entrants were in both the United States and Europe.

At this stage, Japanese firms did not have an important commercial presence in computing (Flamm (1987)). By the late 1950's, however, there were several Japanese technology initiatives under way. What was to be the largest Japanese computer company for some time, IBM Japan, was engaged in protracted negotiations with Japanese government agencies. These negotiations resulted in substantial technology transfer, including favorable licensing of IBM products to the Japanese industry (Anchordoguy, (1989)).

In Japan, entry occurred later than in the United States or Europe. Heavy electric equipment firms (Toshiba, Mitsubishi) entered alongside consumer electronics firms (Matsushita, NEC, and Hitachi) which had capabilities in both areas. Japanese regulatory treatment of telecommunications permitted NTT an active role, encouraging its suppliers of communications equipment, notably Oki Electric and Fujitsu, to enter as well. No Japanese business equipment firms (like IBM or BTM overseas) entered. Thus, Japanese entry differed in being later and purely electronically based.

The three types of entrants reflect the specific technological and market features of the new worldwide industry. Computers were a new electronics good which attracted several existing electronics producers already active in other electronics fields. Similarly, some of the first applications of computers were in business, attracting firms with established connections to business data processing. Interestingly enough, the tension between technology-based and market-oriented firm organizations and competencies was going to reappear throughout the history of the industry. (Davidow (1986)).

Despite the early enthusiasm, there remained fundamental uncertainty on the technological development of the industry, the range of applications, and the potential size of the future market (Rosenberg (1995)). The nature of commercial use of computing and the potential size of the market were unclear. Similarly, the appropriate business model and strategy for a computer company were not known. In particular, it was not well established whether the primary usages for computers would be in making calculations or in processing data. Neither was it certain whether the largest demand segments would be military, scientific/engineering, commercial, or other. These uncertainties meant that the most important directions for technical progress, such as the relative importance of calculation speed vs. storage access, were unclear. They also meant that the nature of buyer/seller relationships and of commercialization efforts were unsettled.<sup>10</sup>

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<sup>10</sup> See Katz and Phillips (1982) and Usselman (1993) for a discussion of this uncertainty with particular regard to how it impacted different firms in the industry.

During the 1950s, the three types of entrants—office equipment producers, electronic firms, and new firms—had distinct capabilities and distinct strategies, which were similar in Europe and the United States for each group of entrants. The electronics-based firms faced the challenge of either building or acquiring a business-equipment marketing capability—including a substantial field sales force—or finding a way to succeed without it.<sup>11</sup> Many found the potential profitability attractive enough to overcome this barrier.<sup>12</sup> Firms with business equipment capabilities quickly recognized the need to add technological ones. Some, like Remington-Rand or National Cash Register (which bought CRC), attempted to obtain these capabilities by acquisition. Internal development of technical capability was the more common strategy, undertaken by IBM and Burroughs in the U.S. and by Olivetti and BTM in Europe.<sup>13</sup>

To succeed, startups such as CDS, SDS, DEC, or Eckert-Mauchly would need to develop both technical and marketing capabilities. Many startups focused on the more technical side, producing computers only for specialized uses. Firms of any type would need remarkable financial resources because neither the technical nor the marketing capability could be built without considerable capital.

In Europe, some firms focused on niche strategies: Nixdorf, Zuse, Telefunken, and so on. From the beginning, Nixdorf had the goal of producing small computers for specific uses. In 1952, Heinz Nixdorf founded the *ALabor fur Impulstechnik* (which only in 1968 changed its name to Nixdorf). Nixdorf developed the first vacuum tube calculator for accounting for RWE and then built several computers for Bull and Wanderer. By this route, a capable computer firm in the small-user niche was built.

Among office equipment firms, a major tension arose between the established mechanical and electromechanical core competencies and the new emerging electronic ones. For example, the office machinery producer Olivetti entered electromechanical calculators in 1949 by creating (with Bull) a commercialization company for the distribution of Bull's tabulating machinery. In the early 1950s, it started doing R&D on electronic computers in various locations in Italy and the United States. Conflicts between the dominant mechanical competence and culture of Olivetti and the emerging electronic one took place since the beginning. The new Electronic Division and the new factory that was going to produce the first electronic calculator, the ELEA 9003 (developed in 1959), were

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<sup>11</sup> One class of technically capable potential entrants, telephone companies, did not enter. In the United States, AT&T's entry was blocked by an antitrust consent decree.

<sup>12</sup> Siemens, for example, decided on a full scale entry in 1954, focusing on mainframes for commercial and scientific uses. At the end of the 1950s it produced the first 2002 computer. It must be noted that during the 1950s Siemens contacted IBM for cooperation in computers. Actual cooperation, however, was limited to the supply of readers of punched card and magnetic tape machinery and did not include mainframes (Malerba (1985)).

<sup>13</sup> For a discussion of BTM and Ferranti, see Freeman (1965), Malerba (1985), and Usselman (1993).

located near Milan, far away from the central headquarters in Ivrea in order to be isolated from the prevailing mechanical culture.

### **2.3 American Government Encouragement of (Domestic) Industry Development**

Substantial government backing for the early U.S. computer industry offered advantages to firms in the United States. There is little support, however, for the view that the U. S. government bought success for IBM and no support whatsoever for a strategic trade policy view of U.S. government actions.

Some of the purely technical capabilities needed to build computers were backed by Federal, especially military, research funding. Technologies such as transistors and core memories were developed in laboratories - AT&T's and MIT's - before the semiconductor industry took off in the mid-1950s. Some of these developments were heavily dependent on Federal money (Flamm (1987)). Further, many early U.S. computer systems were themselves directly supported by federal research funds. In this manner, the Army supported ENIAC; the Navy and Air Force supported Project Whirlwind at MIT; the Census Bureau supported UNIVAC, and so on.<sup>14</sup> Further, it was clear that the military was going to purchase many computers from domestic suppliers. At a broad, general level it is clear that this environment worked to the advantage of IBM. Government support of technical capability development meant that IBM's existing marketing capability could be integrated into a full Chandlerian three pronged investment more effectively. Indeed, many of the technical developments for defense computing were commercially useful. Ultimately, the Defense Calculator became the IBM 701; much of SAGE was valuable in SABRE; and so on. Similarly, reduction in uncertainty and increases in general technical knowledge obtained from defense computers may have been valuable commercially.

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<sup>14</sup> Flamm in chapter 3 tabulates military research support in detail.

Yet this dual-use or spillover story was not, in fact, an important factor in IBM's success. The U.S. government actions were far removed from intentional strategic trade policy aimed at creating a national champion: IBM. Defense Department agencies supported the development of a domestic computer industry.<sup>15</sup> National defense goals, however, could easily have been met by a largely technical computer industry, with marketing capabilities focused on defense procurement procedures. Indeed defense support for computer systems development at IBM (including the Naval Ordnance Research Computer-NORC) and for the 701 Defense Calculator (which was financed by IBM but pre-sold to defense customers) was a small fraction of total IBM's effort. Furthermore, government funding at Eckert-Mauchly Computer Corporation and Engineering Research Associates, both purchased by Remington Rand, was actually intended to put IBM at a competitive disadvantage.<sup>16</sup> Defense Department, however, did act like a well-funded demander with a real need for computer-based weapons systems, and let the supplying industry structure emerge in the marketplace.<sup>17</sup>

Another branch of the same government, the U.S. Department of Justice, worked actively to prevent the emergence of IBM as the computer industry dominant firm. In particular, the U.S. Department of Justice was systematically against IBM's strategy of strengthening marketing and technical capabilities within the same firm. It therefore worked directly against government support of the three pronged investment. In two antitrust lawsuits, the U.S. Department of Justice sought to characterize IBM's marketing capability as anticompetitive.<sup>18</sup> The 1956 consent decree between IBM and the government had, among other provisions, stark limitations on IBM's use of service bureaus as a sales device. The second antitrust lawsuit, brought in 1965 and contested for over a decade, viewed IBM's service, sales, and support efforts as anticompetitive lockin devices.

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<sup>15</sup> Soviet production of nuclear arms led to very considerable investment in anti-aircraft defenses, whose C<sup>3</sup>I part--realized in the 1960's in the SAGE system--was heavily computer based.

<sup>16</sup> The IBM eye-view of early developments was that they constituted Government Funded Competition. Only because of this threat did IBM reverse its standing policy against Federal research collaborations, using Navy money to design the NORC (Pugh (1995)).

<sup>17</sup> Indeed, Usselman offers a very interesting argument that U.S. procurement policy favored IBM only because it took this form (Usselman (1993)). IBM would not likely have been chosen as the national champion in the critical early phases, nor would a supply side procurement policy have led to the development of the IBM commercialization capabilities.

<sup>18</sup> The 1956 consent decree between IBM and the government had, among other provisions, stark limitations on IBM's use of service bureaus as a sales device. The second antitrust lawsuit, brought in 1965 and contested for over a decade, viewed IBM's service, sales, and support efforts as anticompetitive lockin devices.

The legislative branch was also anti-IBM, tilting procurement policy against IBM. Here the issue was more political, having to do with spreading out government procurement funds to states where IBM was not as important an employer as other system companies.<sup>19</sup> Besides, IBM did not initially understand the power of a single computer architecture which could serve both military and business clients and did not expect its Federal support to provide spillouts to its commercial data-processing business. In the critical early stages, IBM had separate development efforts and built separate capabilities to pursue new military/scientific customers and to supply its traditional business/commercial customers because it conceived these two lines of business as distinct.<sup>20</sup> It therefore appeared to believe that electronics offered good opportunities for both commercial and governmental business.<sup>21</sup>

Only *ex post* was it clear that the industry was one in which technology was general purpose. Spillouts from one use to another eventually proved to be significant but not anticipated at the time.<sup>22</sup>

In conclusion, government policy was only accidentally favorable to the creation of IBM as a worldwide leader. Parts of the government opposed IBM's most critical investments. The supportive parts of the government were passively pursuing their own policy goals and were not following any type of strategic trade policy. No one, not even IBM, saw the implications of the positive role of government support for business applications.

### **3. The rise and persistence of IBM world dominance in mainframes**

In the late 1950s and early 1960s, IBM became the world leader in mainframes, and remained so for thirty years. IBM was able to be highly innovative in mainframes, addressing the demand coming from big or medium size users, government, and universities. Three stages can be identified: the rise to worldwide leadership through a high commitment to the Chandlerian three pronged investments; the consolidation of leadership through innovation in a modular product line (IBM System 360); and the continuation of its dominance through waves of highly successful products (IBM System 370, etc.).

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<sup>19</sup> There is an active debate on whether government agencies were able to evade the law and procure IBM as they saw fit. See Greenstein (1992). There is no debate about the anti-IBM policy itself.

<sup>20</sup> See Usselman (1993) on the distinction between IBM's facilities at Poughkeepsie and at Endicott.

<sup>21</sup> See Pugh (1995) on the discussion about IBM initiatives in making its tabulating machines more electronics in the late 1940s, based on beliefs about the future of the tabulation business. See also Katz and Phillips (1982) on the observation that IBM understood that commercial as well as defense applications might be useful early on.

<sup>22</sup> Indeed, spillouts to IBM's commercial business from its defense business were important. See Katz and Phillips (1982) or Flamm (1988) for an accounting of some very important technical developments first appearing in defense sector products.

### **3.1 The generation of IBM world leadership: the role of the three pronged investments**

In the 1950s and early 1960s, IBM introduced highly successful families of computers such as the 701 (1952), 650 (1954) and the 1401 (1960).<sup>23</sup> Each of these new families involved considerable development of new computing technology, not only processing power but also peripherals. Moving from defense calculation to business data processing, IBM supported business systems very effectively at customers' sites, and built a capability to address customer wants and needs. This combination of technical drive and customer focus was difficult to achieve, requiring new management structures. IBM's success sprang from its major R&D investments and more generally, the Chandlerian three pronged investments (managerial capabilities, technology, and marketing).<sup>24</sup> IBM rapidly became the world market leader because of its continuous R&D effort in developing new products, coupled with advanced manufacturing capabilities, excellent marketing competence, and management structures keeping technology and market aligned.

Though much of the attention of the early computer industry was placed on technical calculations for military and scientific purposes, commercially-oriented companies like IBM and Remington Rand were quick to move toward business uses. This movement was not simple, however. Within IBM management, there was wide resistance to building a general purpose computer on the grounds that demand was limited. In the very early 1950s, creation of a computer such as the 701 would call for a large financial commitment and much R&D. This was to be a stored-program computer, able to use the binary number system instead of the decimal, and would be pre-assembled by IBM for rapid setup (and later rapid upgrades) at the customer's site. All of these features called for new, and expensive, technological and production capabilities. The resistance was overcome by IBM's new leader, Thomas Watson, Jr., and IBM's 701 quickly overtook Remington Rand's Univac, the leading computer at the time. The 701's combination of advanced technology and customer-aware features like rapid setup were well matched to IBM's strong marketing presence (already built with tabulating card machines) in business data processing.

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<sup>23</sup> This section draws heavily on Fisher et al. (1983),  
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<sup>24</sup> See Usselman (1993), Sobel (1986).

The resistance within IBM continued with the IBM 650 Magnetic Drum Calculator, which was to become the Model T of computers (Cuthbert Hurd).<sup>25</sup> Many IBM managers thought that the computer's rental price, over \$1000/month, would limit demand too sharply to cover the large development costs. IBM was making progress on a broad technical front: the 650 had 1000 10-digit words of memory, and vastly improved diagnostics, for example. Optional features made it more suitable for calculation or accounting. Accounting reports called for developments in a wide variety of peripherals, including printers, magnetic tape storage, and magnetic disk drives. IBM could offer customers an integrated solution, having made progress on the computer and the variety of peripherals. After being pushed forward into the marketplace, the 650 became the most successful computer of the 1950s, with about 1800 units shipped.

The importance of integration and of wide technical progress continued to be important throughout the decade. The IBM 1401 was, indeed, much faster and more reliable than the previous generation 650. Perhaps more important for its use as an accounting machine was the breadth of peripherals. It could use both punch cards and magnetic tape, worked with the simultaneously introduced 1403 chain printer. Sales of this machine were approximately one quarter of stored-program electronic computers.

On the marketing side as well, IBM pushed ahead. The company made an early and expensive commitment to field service and support, and to customer education. This took place in an era of widespread ignorance about the potential uses of computers. This marketing commitment was not only domestic. IBM succeeded in dominating the European as well as the Japanese mainframe markets. In Europe, IBM's superiority in products and customer assistance was coupled with a local presence on the main markets. For example, IBM UK and IBM Germany tried very hard (succeeding to a large extent) in being considered respectively a British and a German company. In Japan, IBM Japan was for a long time first in revenues among "Japanese" computer companies. The strategy reflected powerful marketing forces. IBM used the "IBM World Trade" model, making itself as local a company as possible. This meant involving nationals in almost all roles, including senior management. The point of this extreme localization was to ensure that relationship selling efforts worked.<sup>26</sup> The scope of IBM's three pronged investment was global, with worldwide exploitation of scale economies in designing and building computers linked to a local marketing organization.

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<sup>25</sup> Interview, Winter 1995.

<sup>26</sup> In the mid 1980s, IBM Japan was replaced by IBM Asia/Pacific, a less Japanese entity headed up the U.S. expatriates.

IBM certainly did make large mistakes. The STRETCH committee, an effort to advance its technical capabilities and to build a high-speed computer, turned out to be a commercial failure. IBM used many of the technical lessons it learned in STRETCH in later products, but did not recover its development expense from the project itself.<sup>27</sup> Yet overall it succeeded in developing a very strong technological and marketing potential.

The computer business in its early phases took place in a competitive environment under tremendous increasing returns to scale. All of marketing, technology, demand and company business model were still to be invented. Since the first two were quite expensive and the last two very uncertain, investments were highly uncertain. From a company perspective, IBM pushed forward with very expensive investments in technology, marketing, and management, thereby putting tremendous pressure on rivals' capabilities. As a consequence a very concentrated structure with a single dominant firm emerged.

### **3.2 The consolidation of IBM world leadership: IBM system 360**

By the early 1960s, the main technical features of a commercially useful computer were clear and many of these features were already embodied in products. Important problems remained, however, notably incompatibilities between computers in different families. The final stage in this evolution was the introduction and implementation of the completely modular, compatible computer family. This was the IBM System 360. This product line, and the organization that improved and sold it, became the dominant industry model.

Incompatibilities between different computers forced costs and delay on using companies. In the early 1960s, computers were designed to be used either for commercial or for scientific uses, not for both. If a user wanted to run both applications, he needed two separate machines, support staffs that understood two different bodies of technical knowledge, and so on. In addition, IBM's machines themselves were not compatible across the broad family of processors: a program run on one processor could not be used on another. Users whose needs grew over time could exhaust the capacity of their existing computer and need to reprogram for the next larger model.

IBM's System 360 was designed to solve these user problems. It was, however, neither an easy decision to make nor a straightforward technical feat. Technically, compatibility over a wide range

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<sup>27</sup> Some of these technologies were quite important, including transistors, a parallel architecture, and manufacturing processes needed to integrate many different components.



of sizes and uses of computers changed the design process. Designers could not optimize for specific purposes, but instead needed to be coordinated in the production of general purpose components that could be specialized. Such coordination raised costs and slowed the invention process. IBM appointed a task force called the SPREAD Committee to develop and supervise the project. Developing the new machine required such a big commitment that the venture came to be popularly known as a "bet the company" initiative. IBM virtually employed all its financial, technological, and human capital. Overall, it devoted a larger percentage of its revenue than it (or any of its competitors) had ever spent on any of their projects.

The decision itself was difficult. Designing a new family of computers meant that there would be future compatibility, but implied incompatibility in the present. IBM executives responsible for the 1401, for example, argued that competitive pressures forced an investment in improved 1401s.<sup>28</sup> The decision also meant abandoning investments in products under development, even successful ones.<sup>29</sup> The IBM decision to end the proliferation of product lines and put resources into a single development effort was risky and expensive. More importantly, it showed that the management control structures needed for the three pronged strategy were in place.

The 360 made existing machines obsolete. Even though it was not directly compatible with the existing processors, users found switching irresistible because of the tremendous benefits of the new system.<sup>30</sup> Among the many distinguishing features of the 360 was price/performance superiority not only over IBM's own computers but over the systems of all its competitors. The success of the 360 was immediate and gigantic: more than a thousand orders were made in the first month after announcement, and many more thousands followed.

The introduction of the IBM System 360 drastically changed the structure of IBM and of the overall computer industry. With System 360 the standardization of components and software allowed the exploitation of economies of scale in component production and the consequent upstream vertical integration of computer firms, the supply of a broad line of compatible computers, and the introduction of modularity and incremental modifications in computer design. From a company perspective, this event showed the realization, after some early confusion, of the importance of scale and scope economies in computer design and commercialization. From an industry perspective, the

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<sup>28</sup> After Honeywell introduced its H-200 computer, IBM experienced 196 lost 1401 sales in 8 weeks. At that time, the chairman of SPREAD was also head of the General Products Division, responsible for the 1401. The argument for further 1401 investment lost to the new System 360 concept despite such powerful opposition.

<sup>29</sup> The almost finished 8000 project was labeled a "wrong" approach despite the enormous financial resources already devoted to it and was discontinued.

<sup>30</sup> The irony is that to get its customers into the circumstances where they would not need to switch computer families for over twenty-five years, IBM had to get them to switch at the beginning.

event was even more important. Success of this strategy at IBM defined a level of innovation and commercialization capability to which other firms, worldwide, were going to be compared by customers.

### **3.3 Continued innovation by the dominant firm: the IBM system 370**

The 1970s saw the continued dominance by IBM in the mainframe segment. IBM introduced a new family of computers called System 370. These computers represented considerable technical advance, much of its own-competence destroying. As with the System 360, IBM was prepared to give up the rents on existing product lines and on the technologies embodied in them. Backward compatibility of the System 370 helped to preserve IBM's position, for customers did not see much destruction of their own computer-using competencies. They could and did continue to use IBM machines predominately.

### **3.4 Strategies and evolution of the losers to IBM around the globe**

In the era of the IBM System 370, the scope of geographic product markets was once again worldwide. IBM was setting the standard in two senses. First, competitive products needed to respond to IBM price/performance, software availability, and service and support levels. Second, a critical technology choice was whether to establish an IBM-compatible product line or to attempt a separate, incompatible platform. The IBM-compatible strategy would involve development of expensive R&D and manufacturing facilities. IBM kept these costs high for rivals, pushing the technical frontier with repeated own-competence destroying innovations. The 1970 unbundling of IBM hardware and system software, under pressure from U.S. antitrust authorities, made the IBM-compatible strategy easier in the System 370 era. Yet rivals found themselves followers to IBM, producing specific components for some customers but never gaining control of the system/370 architecture. The IBM-incompatible strategy was even more expensive, for it involved departures from IBM complementary software and support infrastructure. To pursue the IBM-incompatible strategy, a competitor would need substantial marketing expenditures for a field sales and service force, software, and so on, as well as technical capabilities comparable to the leader's. Firms also faced marketing choices: would they compete for mainstream large-company data center customers or find smaller market niches?

Facing IBM success, American, European, and Japanese firms adopted variants of these follower strategies. In the following pages, we show how a strategy of direct competition with IBM using a

competing platform failed, but how niche strategies and IBM-compatibility strategies permitted survival without threatening IBM dominance.

**a. Head to head confrontation with IBM: always a losing strategy**

Some rivals introduced a competing platform, trying to replicate the IBM three pronged investment. This expensive strategy involved the development of a number of computers, each compatible with the others, and development or encouragement of correspondingly compatible peripherals, software, and end-user knowledge. Effective competition by this method involved building two very distinct assets. One was technological: the capability to design and manufacture computers and close technological complements. The other was marketing: the ability to help customers turn computer technology into useful solutions. Such attempts failed all around the world because the electric and electronics companies were not able to develop effective marketing capabilities, while business equipment companies were not able to move the capabilities of the company fully into electronics and to bet completely on the electronic technologies.

This tension between business equipment companies' existing core competencies and electronic technologies is well illustrated by the case of Olivetti. Olivetti's increasing commitment to mechanical office equipment technologies, particularly after the purchase of Underwood in 1959, drained a massive amount of resources and did not allow committing considerable resources to mainframes. Consequently, Olivetti decided to focus on mechanical technologies and traditional office equipment products rather than on electronics and mainframes and sold its Electronic Division to GE (later on sold to Honeywell) in 1964 (Malerba, 1985).

**b. Compatibility with IBM: a losing strategy in the 1960s becomes a survival strategy in the 1970s**

Another strategy available to competitor companies in these circumstances was the acceptance of the IBM System 360 platform standard and the sale of IBM-compatible computers. A related strategy was building IBM-compatible peripherals such as storage devices, taken up by plug-compatible manufacturers (PCMs).

Most of the initial attempts to introduce IBM-compatible computers failed. For example, RCA built completely IBM-compatible computers, the Spectra Series.<sup>31</sup> RCA's initial marketing plan was

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<sup>31</sup> Another example was Honeywell's earlier offer of IBM 1401-compatible machines unfortunately introduced at the time of the System 360 rollout.

built around availability and superior technical features at the time of IBM order backlogs. Reliability problems and other technical difficulties plagued the Spectra through the System 360 era. Though RCA's effort was profitable for a period, the operations were never really large, and were ultimately sold to Univac.

RCA's failure also involved its collaborative partners around the world. In 1964 Siemens, after realizing that its new 3003 Series was already obsolete, started a collaboration with RCA, which was developing the new Spectra 70 series. RCA gave Siemens a license and technical assistance for the Spectra 70 series, which was shipped as the Siemens 4004 in 1965. In the meantime, the IBM System 360 was overtaking the European as well as American markets. For Siemens, the collaboration with RCA proved initially successful at the commercial level: during the 1960s and early 1970s, Siemens increased its market shares (in Germany from 5% in 1965 to 16% in 1972). This was also due to the introduction of a line of smaller processors (302, 304, 305) and the acquisition of Zuse (1966). Later on, however, RCA's withdrawal from computer production (1971) left Siemens without a partner with advanced technological capabilities.

Later on (1970s), with the unbundling decision, the compatibility strategy became more successful. The compatibility strategy was pursued by a group of American, European, and Japanese companies, often related through agreements of various types.

In particular, the IBM-compatibility strategy of Amdahl, Fujitsu, and Hitachi became successful for a long time in the world market. Amdahl, founded by an ex-IBM designer, was in the IBM-compatible business from the beginning. It had considerable success as a market follower. Japanese firms, which had been investing through domestic consortia in computer technologies, began to make IBM-compatible exports. International linkages were important here. Hitachi had a partnership with RCA, and had learned much about the IBM-compatible business from that experience. Fujitsu was lending money to Amdahl from 1972 and later acquired an ownership stake. In an era of IBM dominance of world markets, only Japanese and Japanese-cooperating sellers succeeded in becoming effective followers through the IBM-compatible strategy.

After an initial period, these new compatible entrants made IBM-compatible computers less expensive. This transferred some profits from IBM to customers. However, control of the System 370 architecture, the operating system, and other key software components, as well as the world dominant market share in mainframe computers remained with IBM.

Unbundling by IBM and the monitoring role of American antitrust authorities also made peripheral sales by PCMs somewhat easier. The same forces also made third-part leasing and other financing more widely available. This had the effect of lowering returns to IBM. Makers of compatible computers and peripherals limited IBM's market power and its ability to price discriminate. However, it is difficult to conclude that any of this direct, compatible competition had any immediate impact on industry evolution. IBM retained control of the mainframe architecture and IBM's profitability was not destroyed. Actually, its broader competitive effect was to enhance the attractiveness of the IBM platform to customers.

### **c. Niche strategy: always a survival strategy**

Another strategy was to avoid head-to-head competition with IBM entirely, seeking out a body of customers left unserved by the 360 platform. Three kinds of niches emerged: specialized commercial market niches, governments, and protected domestic markets for the non-U.S. producers.

#### **c.1 Market niches**

In the United States, the most successful versions of this strategy were niche efforts. CDC was very successful with scientific users. NCR found industry-specific niches, notably with smaller computers, in retail trade and banking. In Europe, contrary to mainframe suppliers such as Standard Elektrik Lorenz and Telefunken which exited completely the computer market, some firms decided to enter the market for mid-range systems (comparable with IBM's systems S/32, S/34, S/36 and later AS400). For example, during the 1960s and the 1970s in Germany several firms, such as Nixdorf, Konstanz, Triumph Adler, Kienzle, Dietz and Krantz, started to produce mid-range systems. These mid-range systems were all proprietary, focused on sector-specific applications and with specific software. These companies (particularly Nixdorf) experienced major success until the 1980s. The introduction and diffusion of microcomputers and the emergence of standard bundles led to the rapid disappearance of these firms (see later on the discussion on the crisis of Nixdorf).

#### **c.2 Government niches**

A very important niche was procurement by the government, for both military and civilian uses. In the United States, procurement policy, under pressure from congressman Jack Brooks's government operations subcommittee, was anti-IBM in intention and effect. Honeywell and Univac took advantage of this, and had much more success in the niche market of Federal government

computer purchases than in the broader commercial computer market. In the other countries, every government protected its weak domestic firms from IBM by use of procurement policy.

### **c.3 Niches by leading domestic customers**

In addition, large domestic customers had close relations with large domestic mainframe producers and would buy domestic. A buy-German or buy-French attitude among large firms and large institutions was present during the 1960s. In Japan, large Japanese buyers, whether the government or NTT, were influenced to buy Japanese computers. Throughout the 1960's, import market share in Japan fell steadily as Japanese firms' capabilities grew.<sup>32</sup>

### **3.5 Coevolution in Europe: the decline of the industry and the role of European national champions policies as exit barriers**

Faced by the mounting competitive challenge from IBM, European producers declined in competitiveness. As previously mentioned, European producers either did not invest enough in R&D or did not have advanced manufacturing and marketing competencies. Some of them (particularly old office equipment producers such as Olivetti) continued to have difficulties in absorbing the new electronic technology and culture and did not want to abandon mechanical or electromechanical technologies. Other producers had major productive and coordination problems. For example, ICL inherited two incompatible mainframe product lines, one from ITC and the other from English Electric, and kept them incompatible during the first part of the 1970s, while developing a third (incompatible) line. All three were also IBM-incompatible. The severe crisis faced in the late 1970s and early 1980s led ICL to move to IBM-compatible strategies, reduce its R & D expenditures on mainframes and increase it on other computer types, while focusing on specific markets: defense, retailing, and financial services. Specialization in these vertical markets still characterizes ICL.

Moreover, in their search for international alliances, some European firms chose big losers in the technological and commercial race. We have already mentioned Siemens' links with RCA. Also during the 1970s the main European mainframe producers continued to foster their links with foreign firms, without much success: Siemens with Fujitsu, ICL with Fujitsu, and CII with Honeywell. During the 1980s ICL set up a cooperation with Fujitsu (in which Fujitsu supplied components and semiconductor design tools, while mainframe architecture, design and software were developed by ICL). In 1991 Fujitsu acquired 80% of ICL. Fujitsu, however, did not decrease ICL's R & D

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<sup>32</sup> Above and beyond the IBM patents, most Japanese firms sought overseas partners. Oki Electric had Sperry as a partner from 1963, Hitachi-RCA from 1961, Toshiba-GE from 1964; Mitsubishi-TRW; NEC-Honeywell from 1962. Matsushita never had an overseas partner but had negotiated with Philips before exiting the computer business in 1964. The important exception was Fujitsu, which had no foreign partner at this stage.

expenditures and let ICL follow quite autonomous marketing strategies in Europe. Siemens continued to follow a strategy of international alliances with key producers in mainframes. After the failures of the alliance with RCA and the UNIDATA experience, Siemens' search for a partner led the company to start a cooperation with Fujitsu (1977) by selling Fujitsu's large mainframes under Siemens' label. Moreover, Siemens founded Comparex with BASF (which was already marketing Hitachi's computers in Europe) for the production of IBM-compatible computers. While cooperation with Fujitsu is still on at the present time, Siemens' involvement in Comparex was strongly reduced in 1988.

In Europe, public policies represented a major exit barrier from mainframe production for national champions such as Siemens, CII, and ICL. First, governments intervened by supporting directly or indirectly the mergers between unsuccessful companies in order to create national champions. For example, in 1968 ICL was formed from the merger of International Computers and Tabulators (ICT) (already incorporating the computer operations of BTM, Ferranti, General Electric Powers and EMI) and English Electric Computers (EEC) (already incorporating the computer operations of Elliot Automation, English Electric, Leo Computers and Marconi). In the same period; in France CSF/CGE and SEA of the Schneider Group merged to form CII. Second, increasingly large programs of support were launched in the various countries. The French Plan Calculs (1967-71 and 1971-75), the British Advanced Computer Technology Project (1969), the German First and Second Data Processing Programs (respectively in 1967-69 and 1969-70) channeled a large part of public policy support to CII, ICL and Siemens, respectively (Malerba (1985)). Third, governments protected national champions' markets through public procurement. For example, in 1969 ICL received 94% of central government's orders for computers and benefited by the official government statement to buy from British firms wherever reasonably possible (Torrise (1995)).

There was even an attempt to increase the size of IBM competitors through a pan-European company. Siemens, CII, and Philips formed the UNIDATA joint venture. Because of conflicts among the partners and the struggle over the control of the joint venture, real cooperation never took off and the joint venture ended in 1975.

In spite of their niche strategies and the national champions policies, market shares of European firms remained quite low. For example, in France in 1972 IBM controlled 58% of the installed base, while CII, Siemens and Philips claimed 12% and Honeywell and Bull 18%; in 1980 IBM still had 52% of the installed base of computers (in France), while CII-Honeywell-Bull controlled 31%. In the U.K., ICL's market share declined from 41% in 1968 to 31% in 1985

The effect of protection by individual European governments was to keep an uncompetitive European computer industry alive and sheltered from being destroyed by IBM. These barriers to exit, however, did not lead European firms to launch major policies and investments able to increase their innovativeness and competitiveness, internationally.

### **3.6 Coevolution in Japan: catching up in the 1960s**

Japanese firms, and government policy in that country, behaved very differently. In the early 1960s the Japanese computer industry also lagged behind IBM. In Japan, this situation led to consortia. With help from government procurement policies and large organizations like the telephone company NTT, firms met with considerable success selling computers within Japan. This was not the case in the overseas markets. As a result the country continued to be a net importer of computers. An example of one of the first consortia was the FONTAC project.<sup>33</sup> Planned as an IBM 1401-killer, this 1962-1964 project was late to market, completion coinciding with the next generation (System 360) announcement from IBM. Both government and private firms participated in it.

The second half of the 1960s saw a concerted Japanese attempt to catch up in computer technology. Technology initiatives were not pointed at the turbulent, unclear, and unstandardized early computer market. Instead, the establishment of broadly compatible platforms in the System 360 had made the importance of scale, standardization, and compatibility clear. Japanese companies' technical initiative was coordinated by MITI in the ASuper High-Performance Computer Project.<sup>@</sup>

The Project had the goal of building specifically Japanese technical capabilities in hardware and software. With IBM patents (extracted as a condition of IBM presence in Japan) and a budget, the Ministry of International Trade and Industry had the resources to encourage cooperation. Six computer firms participated. Firms participated in order to achieve more rapid time-to-market, and sought quickly-commercializable machines. MITI favored a higher technological standard (Anchordoguy, 1989).

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<sup>33</sup> See Anchordoguy (1989) and Fransman (1995).



In addition to government sponsored R&D, other Japanese institutions supported this early development. From 1968, NTT was active as a buyer of computers and as a coordinator of computer company developments of systems, e.g. the DIPS-1 system. In particular, NTT supported computers development of three major producers (Fujitsu, Hitachi, and NEC) which were also major telecommunications equipment suppliers.<sup>34</sup> Government subsidized low interest loans to rent Japanese computers through the Japan Electronic Computer Corporation and encouraged many users to select Japanese brand computers (Anchordoguy (1989)). Other users, with both national and private commercial goals, were encouraged to make this selection as well.

The effects of these early initiatives were to build a very substantial technological capability within some Japanese firms, partially catching up to IBM. This, plus market advantage in the home Japanese market, led to substantial import substitution. Japanese vendors' share of the Japanese computers market grew steadily over the 1960's, reaching almost 60% (Anchordoguy (1989)). After IBM's introduction of System /370 this share, however, was substantially reduced to about 50%.

Market success of Japanese vendors was weaker for computer software than for hardware. The creation of the Japan Software Company, a joint venture of the Industrial Bank of Japan, NEC, Fujitsu, and Hitachi, had considerable government subsidy. The firm was not able to ship such key products as the *Common Language* that would let applications run on any Japanese computer. It was dissolved in 1972.

At the time of the worldwide transition from System/360 to System/370, Japan had built strong but not yet worldwide-competitive computer hardware competencies. Incomplete protection from external competition such as from IBM and no protection from domestic competition among Japanese producers had spurred firms' development efforts. Note that both MITI and NTT avoided European-style *national champion* policies. Each worked with a number of companies which protected only one firm and de facto created a barrier to exit in that single firm. Japanese policies, on the contrary, worked with a number of companies supporting their cooperation in some technologies, but keeping them in competition. The presence of both cooperation and competition has been a major reason for the moderate success of Japanese policies compared to the failure of European ones.

### **3.7 Japanese advantages consolidated in the 1970s**

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<sup>34</sup> See Fransman (1990) on Japanese developments, especially NTT's role.

Overtime, changes in the computer market played to Japanese firms' strengths. When IBM unbundled operating system software from computer hardware, Japanese companies' ability to build strong hardware competencies increased in importance, and their software weakness became less important (due to the opportunity to sell hardware alone).

During the IBM System/370 era, Japanese firms held a large share of the domestic market through government, NTT, and Keiretsu customer connections. But they lagged in both hardware and software technologies. In the late 1970's two VLSI (integrated circuit) joint-ventures were launched by several Japanese computer firms, one sponsored by NTT, the other by MITI. These projects were focused on the creation of a Japanese hardware engineering and manufacturing capability. The scope was ambitious, including manufacturing equipment for integrated circuit devices, integrated circuits, and computer hardware. Separate initiatives dealt with the problem of computer software. In this period software initiatives met with little success. As a result major attempts to establish an integrated computer systems company, with both hardware and key software, plus worldwide service, sales and support systems, was largely unsuccessful as measured by world market standards.

The hardware initiatives, by contrast, brought some Japanese firms to the worldwide competitive level. This was reflected in domestic and export markets. Domestically, Fujitsu passed IBM Japan in sales in 1979; by 1982, Fujitsu had 22% of the market compared to IBM's 20%. NEC and Hitachi were not far behind with 17% and 15%, respectively. By the early 1980's, Japan became a net exporter of computer equipment. The exports were largely IBM-compatible mainframes.

As the 1970s ended, the Japanese were by far the most effective followers of IBM. Traditional national competencies, such as relationship selling at home and efficient volume manufacturing for export, were being well exploited.

The next round of consortia technology development efforts were more ambitious. The goal was establishing a computer architecture independent of IBM.<sup>35</sup> This would take Japanese competencies into direct head-to-head competition with IBM, of the form seen above to be very difficult. Accordingly, Japanese efforts involved an attempt not merely to catch up but to leapfrog IBM technologically.

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<sup>35</sup> The 1982 secret-stealing incident, in which Hitachi was caught attempting to buy IBM trade secrets from a consultant, was often cited as proof of the importance of these efforts.

This effort played out in the Fifth Generation Computer Project and in the Supercomputer Project. Again, these were multicompany government- or NTT-sponsored collaborative research efforts. The Supercomputer Project, begun in 1981 with nearly a decade-long time horizon, was a hardware technology-capability project. Involving nine large Japanese computer firms in a variety of subprojects, it attempted to (inter alia) push forward integrated circuit technology in breakthrough areas such as gallium arsenide instead of silicon. While that and other technology-capability goals were clear, the exact design concept for a future supercomputer was left unresolved. Over the same time period, the Fifth Generation Computer Project had more of a computer system development flavor. Its goal was an artificial-intelligence based thinking machine.<sup>36</sup>

These collaborative research efforts have led to much discussion of "Japan, Inc." It is worth stressing the breadth of Japanese mainframe computer companies' activities in this period. While these long term collaborative development projects were part of their activities, they were by far not the most important part. Matching product capabilities with IBM, with Amdahl, and with one another meant that there was plenty of ordinary technological competition. Once again, the appropriate view of Japan, Inc. involves both some coordination by the government and considerable independence and competition among firms.<sup>37</sup>

The Japanese leapfrogging efforts, and Japanese firms' technology development efforts, were once again of mixed success. Some of the longer-term technology initiatives, such as gallium arsenide chips and artificial intelligence software, turned out to be far less fruitful directions than anticipated. Yet the overall effort led to the development of more fully realized three pronged investments--of a Japanese form--by the late 1980s. Many observers saw this development as a very real threat to IBM's dominance. Others saw less of a threat.<sup>38</sup>

The Japanese initiatives never had a real market test, and so offer little hard evidence resolving the debate about the effectiveness of public/private consortia at this more ambitious level. At the end of the 1980s, the Japanese efforts were coming to fruition. At the same time, the first industry

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<sup>36</sup> The SIGMA project, to build Japanese Unix computers and workstations, had a shorter payback span, equal IBM-independence, but still depended on international standards.

<sup>37</sup> Some observers doubt the efficacy of the central coordination. See Callon (1993) for the view that the consortia largely pursued the firms' separate goals, rather than uniting them in a government-led way.

<sup>38</sup> See Ferguson (1993) and Anchoroguy (1989) as well as Sobel (1986) for the view that it was a real threat. Ferguson and Anchoroguy are particularly interested in the government policy issues. Since IBM's strengths were integrative, they argue, could not a whole country coordinate the three pronged investments if it had the right policies? But see Callon (1994) for the view that MITI did not coordinate. Also, see Fransman (1995) for the view that MITI did coordinate but suffered from a vision failure. While MITI has been quite effective in catching-up programs in mainframes through cooperative programs, MITI has been unsuccessful in the perception of developments alternative to mainframes (such as computer networks) or in the creation of radically new technologies.

dynamics was coming to an end. The era of IBM dominance of large-systems computing did end, but it was not the Japanese threat that ended it. Instead, it was competition from networked small computers that attacked the large mainframes. To see the origins of that threat, we now move backward in time and examine the second, entrepreneurial, industry dynamics.

#### **4. Industry Dynamics 2: Entrepreneurship and Entry**

The second industry dynamics, that of the founding and evolution of new firms, new markets, and new technological capabilities, went forward in parallel to the first. It saw, however, radically different coevolutionary processes. We now return to the early 1960s to follow this very distinct coevolution.

##### **4.1 Minicomputers: the sources of American competitive advantage change**

The introduction of the first real time interactive general purpose minicomputer-the PDP8 by DEC in 1965- opened up new types of demand for computers in research laboratories and manufacturing plants (the monitoring and control of industrial processes). In addition, computers were used for technical problem solving activities, and focused on specific applications. Integrated circuits, and not transistors were used from the beginning as basic semiconductor components.

The appropriate seller marketing model for small business and scientific minicomputers was built on the fact that the relevant buyers were technically fluent.<sup>39</sup> The features of computers that mattered to buyers in these segments could be described quickly in objective, technical language. Institutions for direct communication among buyers about products sprang up. These had a strong engineering fraternity flavor, but played some of the same roles as the sales force in the commercial segments. No extensive software support was provided by minicomputer producers, so new intermediate actors emerged between the minicomputer producers and the customers: system houses and value added retailers.

##### **4.2 High entry rates and rapid firm growth in the American industry**

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<sup>39</sup> This contrasts with the mainframe marketing model, with its extensive field sales forces, customer support and service, and relationships with senior financial or operations executives in customer companies.

Minicomputers had a major effect on the structure of the American industry. A large number of new specialized minicomputer firms entered the industry. DEC, the largest of them (with about one-third of minicomputer sales over many years), was an entrepreneurial startup with roots at MIT's Lincoln Laboratory. Other new firms included CCC, Microdata, General Automation and Computer Automation. Because of the importance of minicomputers in scientific instrumentation, many instrument firms, including Hewlett-Packard, Varian, Perkin-Elmer, and Gould, entered the minicomputer market.<sup>40</sup>

Existing computer firms entered minicomputers late and with mixed success: IBM had a small mainframe marketing strategy, not much blessed in the marketplace, while Honeywell (another instruments and controls company) did well. The last source of new minicomputer companies were spinoffs. Data General was formed by entrepreneurs leaving DEC; Prime Computer by executives from Honeywell; Tandem (which might be classified as either a minicomputer or mainframe firm) by an HP marketing executive. Thus, in the early period (through roughly 1975) of the minicomputer market the sources of entrants were different than they had been in the mainframe market.

#### **4.3 Limited entry and slow firm growth in Europe and Japan**

In Europe, few new minicomputer firms entered the industry, and for several reasons. First, American producers had a first mover advantage and rapidly entered the European market. Second, similarly to American mainframe producers, established European mainframe producers did not move or moved too late and unsuccessfully into minicomputers. Third, limited spin off from universities took place. Fourth, lack of venture capital unpaired the financial support for new ventures. Fifth, the protectionist measures used by the European governments for mainframes (such as public procurement) could not be extended to a market formed by small and medium enterprises and research laboratories.

As previously mentioned, during this period in Germany several producers thrived in the market for mid range systems for specific applications. The case of Nixdorf is highly illustrative of this phenomenon. In 1965, Nixdorf introduced the Universal Computer 820, a small computer with a cash register based on semiconductors. Later, it developed several sector specific software solutions which targeted small and medium size firms, mainly for banks and retailing (POS and cash

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<sup>40</sup> While all of these were entrepreneurial companies, they had been founded to make instruments, not computers.

registers) and followed a strategy of direct distribution. For its 8870 family (1973), Nixdorf developed the software Comet which proved to be a major success. During the 1970s, however, the first weaknesses emerged: there was no integration or modularity among the various product lines, internal technology development was limited and product quality was low.

Japanese efforts in the minicomputer business have been largely unsuccessful. The government sponsored SIGMA project of the 1980s, for example, which sought to develop a UNIX-based workstation platform for application software development. It did not reach market success.

## **5. Microcomputers: the sources of American competitive advantage persist**

The availability of a new technology at the component level - the microprocessor-allowed firms to develop products more user friendly and more decentralized in terms of computing capacity and to satisfy the needs of new types of demand: family, hobby, educational uses and small business. Personal computers were far less powerful but also far cheaper than the machines discussed so far. This spread computing power through organizations (beyond centralized MIS) leading to the creation of many new applications.

### **5.1 High entry rates and rapid firm growth in the American industry**

In the United States, the market developed first on the basis of hobbyist demand, with suppliers typically adopting the marketing model of minicomputer producers. In the late 1970s, there were two main de facto standards for personal computers, CP/M and the Apple II. Although the CP/M operating system was itself the proprietary product of Digital Research, it was available on dozens of different brands of computers, most running the Intel 8080 or the competitive nearly compatible Zilog Z80 microprocessor. In these circumstances, the market was quite open to entry. Most CP/M computer firms were entrepreneurial startups. Even an English expatriate, Adam Osborne, was able to found an American startup firm. Osborne computer's strategy of portability was for some time very successful as the firm had a leading CP/M role. The Apple II system had a proprietary architecture and operating system but, was like CP/M, an open one. Software developers could rely on the Apple or CP/M environment to provide a stable platform for applications or utilities development. A large number of independent software companies came into being, again, overwhelmingly entrepreneurial in origin.

Some software products were exceedingly successful and affected the overall demand for microcomputers and the development of the marketplace. Of these, the most important example is

VISICALC, a spreadsheet program. Developed by entrepreneurs when they were students, VISICALC provided a strong motivation for accounting or similar number-crunching workers to acquire microcomputers for direct use in work. Market forces transformed the hobbyist personal computer into the business personal computer.

Entrants resembled those in minicomputers. They consisted largely of established electronics (but not computer) firms, and de novo entrants. They may be divided into specialized computer firms (such as Apple, Commodore, Tandy and Compaq) and clones.

## **5.2 The reaction of IBM**

Established mainframe and minicomputer producers had a demand perception lag compared to new personal computer producers. When IBM decided to move in, it did through external linkages with competent firms: Microsoft for operating system software and Intel for microprocessors. The IBM PC was an advance over CP/M and the Apple II. More importantly, it was a product from long-established IBM rather than an entrepreneurial startup. Other experienced electronics companies entered in the early 1980's as well. DEC and HP made PCs that were IBM-compatible to varying degrees; ultimately the power of the PC standard in the marketplace compelled them to be fully compatible. AT&T also entered with an IBM PC work alike. These entry efforts by minicomputer and telephone firms were not linked to any direct marketing connection between the firms' existing product lines. Rather they were attempts to use general electronics design, manufacturing and marketing capabilities in a growing new area. Mainframe sellers also entered the PC market place, notably Wang, Burroughs, and Honeywell. Their machines can best be understood from a marketing perspective: as a courtesy to existing large-computer customers, the firms offered the new small computers as well.

## **5.3 Competing approaches in PCs and the emergence of the PC platform**

There were other initiatives technically comparable to the IBM PC in the sense that they used 16-bit rather than the previously standard 8-bit microprocessors. Apple, by then an established company, introduced the Apple III. This system, which is much more PC-like than Macintosh-like, gained considerable early enthusiasm in the marketplace. Apple had great difficulties, however, building reliable Apple III systems. Another initiative also had elements of standards continuity: CPM/86. The "86" label here means that the operating system ran on Intel 8086 microprocessor: it was a 16-bit system with some multiprocessing capabilities. Other entrepreneurial startups had, for

some time, success in the 16-bit world: consider, for example, Cromemco (a startup named after a college dormitory).

As extensively documented by Langlois (1990), the potential for many 16-bit initiatives were swept away by the IBM PC standard. This product was both architecturally open and affiliated with the IBM brand name. Only Apple's third effort at more advanced personal computing, the Macintosh, (technically very different from Apple III, and much cheaper than the little-documented Lisa system it replaced) was successful in the marketplace. Macintosh enjoyed very substantial product differentiation advantages. Though it was designed as "the computer for the rest of us," that is, as a machine that would have a broad mass market of unsophisticated users, the Macintosh succeeded initially as a niche product for users (such as marketing departments running desktop publishing software) who valued its graphical capabilities.

#### **5.4 Firms= strategies in the PC platform world**

The shift from entrepreneurial companies supply to an IBM branded supply reflected the changing nature of demand, and was widely bemoaned. The relevant chapter of Freiburger (1984) calls this era "The Arrival of the Suits", that is, the replacement of technologists with businessmen as the suppliers of personal computers.

IBM's decision to open the PC architecture traded off future competition for present speed in reaching the market and the standard-setting benefits of openness. Future competition was going to come from other manufacturers of PCs themselves. For a period, however, neither other brand-name PCs from other electronics producers nor "clones" from startups were an effective source of competition for IBM

##### **a. The branded clone strategy**

New successful strategies emerged during the second half of the 1980s. The branded clone is one. After 1986 and the move of Compaq into branded competition, entrepreneurial startups began to compete with IBM on a more effective basis: firms with strong technical bases such as ALR and AST were, like Compaq, able to shift to having a brand presence. Entry with specifically marketing or distribution advantages, such as that of Dell, was another route. Many overseas firms followed this same path. ACER, for example, first built technical competence in Taiwan as a producer of "clone" computers, often with other firms' brand names on them. Only later did ACER attempt to build its own export brand name. The extent and pace of this increase in competition in the PC



segment was difficult to foresee at the outset, if only because the size and growth of the segment, which drew much of the entry, were significantly larger than anticipated.

### **b. Competition from complementary technologies**

Perhaps, a more important source of competition, and certainly unanticipated at the time IBM chose the open architecture, came from makers of complementary PC components. In particular, the technological leadership determining the direction of technical advance of the PC came to be divided among

- (1) makers of computers, of which IBM was the largest and most influential;
- (2) Intel, maker of the microprocessors in the PCs,<sup>41</sup>
- (3) Microsoft, maker of the operating system for PCs.<sup>42</sup>

Divided technical leadership reduced IBM's ability to steer the direction of PC technical change in c

Despite competition from the other technological leaders and from other PC computer manufacturers that limited IBM's market power as a PC firm, the PC platform was an effective competitor against other ways of supporting first "individual productivity@ applications and later small business and small department multiperson applications. The market, not any individual firm, determined most of the rate and direction of technical change in the platform. The market had on its side great economies of scale, not only in the production of individual components, but also in the (external) economies arising from network externalities (Langlois (1990)). In all computer markets seen to date, success for a platform meant leveraging up suppliers' efforts through customers' complementary investments. In personal computers, this took a new form. Instead of tight bilateral marketing relationships between a platform vendor and the customers, external economies flew through the compatibility of independent software vendors' (ISVs) products with a platform, and with the pool of knowledge of how to use the platform and its software. Literally millions of users collectively participate in these external economies, each having only a weak direct link to suppliers. The aggregate strength of the leverage for the platform is at least as large here as in the mainframe case.

### **5.5 European industry: limited entry and survival only in niches**

In personal computers the success of European firms has been limited for reasons similar to

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<sup>41</sup> Competition from licensed clones of Intel chips, such as AMD, was largely irrelevant to the determination of the technical direction of the platform. Competition from almost-clones, such as the NEC V-series, was important in some local markets but never as influential as the Z80 had been earlier on.

<sup>42</sup> Again, competition from other terms which were licensed to make versions of the operating system, such as IBM, was largely irrelevant in terms of Microsoft's role in setting technical direction.

<sup>43</sup> As IBM's failure to establish MCA or OS/2 clearly show.

the ones discussed for minicomputers. American microcomputer producers had a first mover advantage and rapidly entered the European market, while established European mainframe producers moved late and unsuccessfully into microcomputers. Moreover, outside the U.K. the lack of venture capital and the low spin-off from universities limited the rate of European entry.

The entry of American microcomputer producers in Europe eliminated all the German firms which had entered midrange systems during the 1960s and 1970s. Nixdorf is a case in point. The introduction of personal computers substituted midrange systems in several applications. In addition, Nixdorf's proprietary systems contrasted with open systems or IBM-compatible strategies of several PC producers. Moreover, some of the weaknesses of Nixdorf (already discussed above) became more relevant during the 1980s: a late attempt to enter the PC market, a presence in too many vertical markets (cash-registers, banks, manufacturing, EDP-centers and communications) with too limited internal technological competencies and high reliance on external technology, and a limited renewal of the most successful products.

The main European mainframe producers, such as Siemens and ICL, entered the PC market late and have not been highly successful. Siemens entered personal computer production in 1985, while only in the 1987, ICL (after the unsuccessful development and production of CPM and CDOS small and medium systems during the first part of the 1980s) decided to move to MS-DOS by developing MS-DOS PCs in collaboration with ACER. Both Siemens and ICL undertook acquisition processes in order to strengthen their competencies in PCs and in related fields (software and communications). In 1989 Siemens bought Rolm from IBM, while in 1990 it acquired ailing Nixdorf. In 1991, ICL-Fujitsu acquired Nokia Data System Division.

As in the minicomputer case, few new entries into the microcomputer market came from European startups. The U.K. represents an exception (Torrise (1995)). Here the presence of Cambridge University, Cambridge Science Park, technical societies such as the Cambridge Computer Club, high rates of spin off from established British computer producers and foreign-owned firms produced relatively high entry of new firms (such as Amstrad, Acorn, Sinclair, Cambridge Computers, Apricot and Psion) in the markets for personal computers, home computers, school computers and palm-top computers.

Niche strategies have been followed by most new European entrants (Torrise (1995)). Amstrad represents a case of successful diversification from consumer electronics into low-price products (Thomas (1990)). In 1984, Amstrad, a consumer electronics firm founded in 1968, entered the personal computer business by introducing manufacturing, marketing, and sales techniques that

were popular in the consumer electronics business. Amstrad followed a very aggressive export strategy and targeted the European market by offering low-price, advanced design systems with standard components. Recently, Amstrad's strategy of low-price products with low R&D and lack of a dealer network faced difficulties with the entries of clone producers and of high quality-low cost producers such as Atari and Compaq. Psion is an example of innovative entry by a scientist. Contrary to Amstrad, Psion was founded by a scientist from Imperial College in London. After developing software games for home computers, the firm introduced the first hand-held computer-the Organizer-in 1984. The firm grew internationally by specializing in hand-held portable computers and software for the home, professional, and retail markets. Psion was able to develop advanced competencies in design, engineering, logistic and manufacturing. It used direct marketing, sales forces, and retail channels. Psion is now pursuing the integration between hand-held computers and radio communications. Finally, Acorn represents a case of rapid identification of a growth area in a protected niche market. Acorn was established in 1982 as a consequence of the launch of BBC's new educational programs and the Department of Education's decision to start IT diffusion programs in the national school system. After a period of success, the increasing competition in the home computer market led to a period of crisis for Acorn, which was then acquired by Olivetti. Later on, Acorn developed a new RISC microprocessor for personal computers.

Only one major office equipment producer successfully entered the standard PC market: Olivetti. In the Olivetti case, however, this entry into PCs represented a re-entry into the computer industry. After its exit from mainframes in the mid-1960s, Olivetti's electronic competencies did not disappear completely with the sale of its Electronic Division to General Electric. In 1965, the small group of electronic researchers who remained in Olivetti developed a desk-top electronic calculator (Programma 101) for business and technical applications. The P101 was innovative because it had a low price (1,000 dollars), was programmable, and did not require specialized personnel for its working. The P101 did not use integrated circuits, but instead automatically assembled ad-hoc logic components. The P101 had such a tremendous commercial success that Hewlett Packard paid royalties to Olivetti for the development of its HP 9100, very similar to the P101. The P101 remained an isolated case in the stream of Olivetti mechanical desk-top calculators of the 1960s. Actually, in 1968, a new advanced mechanical calculator, Logos 27, was introduced by Olivetti replacing the P101 (Torrise (1996)). Due to the collapse of the mechanical and electromechanical office machinery market of the 1970s, Olivetti reentered in the computer industry in 1978. The advantage of not being a mainframe producer (and of having some internal electronics competencies) produced a successful

entry into microcomputers. After having produced the first electronic typewriter (1978), Olivetti moved to automatic teller machines and photocopiers, and finally to personal computers. In 1983, it introduced the M24. In order to support and strengthen its entry into microcomputers during the 1980s, Olivetti followed a strategy of international alliances and opened up a wide range of cooperative agreements. Two major ones with AT&T and DEC were later on terminated.

In this period, traditional European policies could not be effectively used in an attempt to maintain unsuccessful producers in the market, as they were in mainframes. National champions policies in fact proved quite ineffective as barriers to exit, because demand was controllable only to a very limited extent by public procurement and domestic supply could not easily be sheltered by protectionist measures.

### **5.6 Japanese industry: limited entry in a fragmented domestic market**

The Japanese PC industry was characterized by Japanese firms' efforts focused on the local-market in a time of worldwide standards. As a result, Japanese PC hardware exports were small and PC software exports near zero. In 1992, PC domestic shipments were roughly two million units, exports roughly a million. Many of the exports were based on manufacturing and design capabilities for complex electronic artifacts, such as the Toshiba notebooks and laptops.

The Japanese PC market has yet (early 1995) to adopt the IBM/Microsoft/Intel PC standard. A NEC almost-world-standard design has had the largest market share. In the early 1990s, NEC held a very large share of the Japanese PC market (53% in 1992) (Dataquest in Fransman (1995), p.270). The reasons for this success are several: NEC developed its PC in a decentralized way, kept its core competencies in-house, used new marketing channels (such as Bit-Inns and Microcomputer Shops), developed new advanced PC software applications, and pushed compatibility across products such as NEC PC-8000 and NEC PC-9800. Being also a major telecommunication and semiconductor producer, in the process of PC development NEC was favored by the in-house lack of a dominant mainframe culture (see Fransman (1995) for a detailed description of NEC's involvement in PCs). Based on almost-Intel microprocessors, and an almost-IBM-PC architecture, these computers neither gained much connection to worldwide external economies nor obtained the production scale economies of the standard PC. A strong competitor, possibly because it is more graphical and thus more linguistically flexible, has been Apple Japan.<sup>44</sup>

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<sup>44</sup> The Open Architecture Group, which includes Toshiba and Fujitsu, has been attempting to establish the worldwide PC standard in Japanese.

Another very interesting contender for the Japanese market standard during the 1980s was TRON. A collaborative effort, neither government nor NTT sponsored, TRON was intended to be an all-Japanese microcomputer system. From a new microprocessor through to a Japanese-character set (kanji) user interface, TRON would permit complete separation from the world market.

Language differences, and specific market conditions, mattered. For the evolution of the Japanese industry until the 32-bit era, PCs could only accommodate Kanji in very clumsy ways. Also, a separate software market did not develop in Japan. The domination of the mainframe market by Fujitsu, Hitachi, and NEC led to the development of customized software which then hampered the development of standard package software. Even microcomputers were marketed in Japan the way mainframes were in most other places: they came with bundled software, or specific application software written for the individual user site.

Whatever the origins, the effects were to have a fragmented, specifically Japanese domestic market (Cottrell (1994)). Software and hardware producers in Japan faced little competition from international computers. But with a domestic market substantially smaller than the world market, the Japanese industry was unable to participate in worldwide scale economies and substantial external economies associated with microcomputers.

## **6. Computer systems and networks: the sources of American advantages change again**

The 1990s saw three linked changes in computer industry structure and the workings of competition. The process of vertical disintegration, which had been historically confined to making each new market segment less integrated than the last, spread to all the segments. The locus of rent generation shifted downstream to software and applications developments. Computer hardware itself became more of a commodity. Finally, the existing rents of mainframes and commercial minicomputers came under intense competitive pressure from networks of smaller computers, in Aclient/server®, and related configurations. This change is important enough to be treated as a third industry dynamics.<sup>45</sup>

### **6.1 Open platforms connectivities and complementarities**

During the 1980s, computing platforms with open interfaces, such as the IBM/Intel/MS-DOS PC and Unix workstations, became important and took on their own industry dynamics. They allowed

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<sup>45</sup> See Bresnahan and Greenstein (1992) for the causes of the new dynamic.

interchange-ability, connectivity, and interoperability in hardware and system software. Local Area Network (LAN) standards for connecting PCs also began to emerge; while less than fully open, they were far more open than earlier vendor-specific networking interfaces. All this was based on the vast scale of the PC market. Parallel movements in Unix/workstation computers and in Internet networking standards took place in universities and scientific communities.

The existence of open interface standards and of specialized technology firms were mutually reinforcing. Standard bundles allowed new software firms to compete in the system software market or in the application software market (which could be packaged or custom) without producing hardware. Entrants would offer whole new systems by fully developing and producing hardware and software (hardware manufacturers), by integrating different parts of the system for specific applications (systems integrators), or by offering specialized software for specific applications.

In a context of standard bundles and application software, the key dimension for successful innovation became the ability to use complementarities by linking technology, users, and applications. It must be noted that application solutions, custom software, and software services required a knowledge base for innovation different from hardware production: an in-depth understanding of end-uses of information systems in terms of horizontal applications (such as spreadsheet or word processing), vertical applications (such as software for banks, transport, and so on), and specific users applications (custom software). Therefore, in order to be successful in applications, firms had to understand market needs, identify the relevant dimensions of specific market applications, target their products to those dimensions, and interact with users on a continuous basis.

Growth in the new, client/server architectures changed the linkages between a successful computer product and technology sellers. Now, computer systems development would involve at least the choice of computers as clients and other computers as servers plus software and networking technology to integrate them. Integration services, not unlike traditional systems development services in mainframe use, would be needed as well. Unbundling of clients from servers meant that market forces could have a stronger effect. The existence of de facto market standards in the standalone small computer markets for microcomputers and workstations meant that most new system developments would take advantage of the considerable technical advances in Intel/IBM/Microsoft based microcomputers or in Apple computers (a smaller number of systems used Unix-based clients). Similarly, the unbundled client meant that de facto standard software for microcomputers could be part of large-systems development. The ease of use and familiarity of small computer systems were developed in the market for individual productivity applications and now

were redeployed in the market for multiuser departmental or company-wide applications.

Unbundled from the client, and the related software, the large computer formerly defined the computer system became a "server." Servers were rated by technological functionality in performing a variety of "service" tasks: the "file server", "database server", and "application server". As a consequence, the traditional marketing strengths of large-system vendors like IBM were devalued. Close relationships with customers became of little use in selling a standard product.

Computer industry structure underwent, and is still undergoing at this writing, a dramatic shift. The shift has been large enough for some participants and observers to talk of an *old* computer industry in distinction from a *new* computer industry. The two are different along a wide variety of dimensions: firm organization, industry structure, technical base and the key technologies for defining the direction of the industry. Roughly speaking, success has shifted from a model with vertically integrated firms closely linked to their customers selling integrated products as *solutions* and called *computer* companies because they made computer systems. Success has shifted to a model of specialized technology-selling firms, with customers (or their systems integrators, consultants, or outsourcers) putting together their own systems from components, and *computer* companies that do not make any hardware. These changes have been accomplished with a huge turnover in the rankings of successful firms.

Consequently, a process of vertical disintegration has taken place in the industry. In addition to vertically integrated producers in hardware, system software and application software, such as Apple and IBM, specialized firms emerged. Given the complexity of the knowledge base required for innovative activities and the heterogeneity of competencies, cooperation among firms and networking strategies became quite widespread by providing complementary and specialized expertises regarding computer hardware or basic operating software, features of specific applications, characteristics of market niches or user requirements.

As yet, no universally accepted standards for networking computers into client/server architectures have emerged. Firms with client standards as their competitive advantage (Microsoft), others with strong server positions (Oracle, IBM), and yet others with networking competencies (Novell, IBM again) compete to influence the *de facto* standards setting process. Once again, we see entry of a wide variety of organizational forms with a wide variety of competencies. In pursuit of the same rents we predict the shake out with little fear of future contradiction.

## **6.2 The United States: success from complementarities, knowledge externalities, and**

### **variety in experimentation**

Again, country advantages remained in the United States, but for reasons that differed compared with mainframes, or mini and micro. As we have seen before, in mainframes one world leader emerged. American advantages coincided with IBM advantages. In mini and microcomputers, on the contrary, entry conditions and an environment conducive to rapid growth of new firms was at the base of American advantages. For networked computing, the sources of American advantages shifted again. Networked computer systems were highly complex and rich in opportunities in all their various components and dimensions. No single firm could innovate in all parts and subsystems. Open platforms and standard bundles permitted compatibility and connectivity among various artefacts introduced by the specialized firms in the various layers and also system integration by some firms or even by users. The new specialized entrants were of various types: spin-offs from established computer firms funded by some venture capitalists (technological competence driven), science-based firms established by University scientists and funded by some venture capitalists, new firms with market or marketing competencies.

The presence of strong complementarities and local knowledge externalities gave major international advantages to the United States or more precisely, to Silicon Valley, which had several firms at the frontier in each market layer. Intense formal and informal communication and high personnel mobility (together with the high entry and growth rates already present in the mini and micro period), allowed firms located in the United States (particularly in Silicon Valley) to be exposed early on to new experiments, knowledge, and technologies. These firms could rapidly take this new knowledge into account in their new artefacts. Relatedly, they could feed their new developments to the other producers in the same or in other layers and to system integrators. Therefore, positive feedbacks and knowledge increasing returns among producers within and across vertical layers were being created. These mutual positive feedbacks gave American firms major innovative advantages over competitors located in other areas.

Some American established computer producers (such as IBM) had to reorganize themselves into application oriented groups. Others had a less successful transition. Honeywell was acquired by Bull and pulled out of the general purpose mainframe market. CDC experienced major difficulties. Burroughs and Univac merged to become Unisys. The combined company, however, soon exited the computer business, leaving behind the former marketing organization which became a systems integration firm.



### **6.3 Europe: survival in niches**

Europe did not have firms active at the frontier in several of the layers of the new computer industry, as the United States did. As a consequence, local knowledge externalities and positive feedbacks did not take place. Therefore, entry of European firms has been mainly related to niches in system integration (Malerba (1992)) and custom software (Malerba-Torrise (1996)). Cap Gemini Sogeti has been the most successful firm in this realm. In hardware and system software standard bundles as well as in software package applications, new as well as established American firms continued to be market leaders. Among European producers, only SAP and Software AG have been successful.

In order to survive in the new industry, large established European computer firms tied themselves up with key microprocessor producers. Bull acquired Honeywell, teamed up with IBM by using its RISC microprocessors and increased its commitment to UNIX. Siemens followed a strategy of internal growth and acquisitions (Nixdorf) and joined IBM's Power PC initiative. Finally, ICL, acquired by Fujitsu, increased its links with Sun (RISC architecture).

In addition, all the main European computer producers moved into vertical markets and applications: Siemens-Nixdorf in banking, public institutions, universities, hospitals and infrastructure; ICL in distribution. After an unsuccessful attempt to team up with DEC (Alpha processors), Olivetti exited from the PC business in 1997 and focused on software and system integration in banking, office information systems, and distribution. In addition, it entered forcefully in the mobile phones market.

The internal market program of the EC, through the dismantling of trade barriers, the harmonization of technical norms and the setting of European standards have attempted to create a homogeneous market, therefore increasing the incentives for entry and growth of successful European producers in niches not already occupied by American producers. Also, European R&D cooperative policies such as Esprit and Eureka have proved somewhat successful in developing European standards, fostering additional communication and interaction among domestic producers and teaming up (private) resources for entry in new advanced and expensive technologies. As in the Japanese case, the evidence on the effects of these European cooperative policies on the successful development of new products (Malerba (1992)) is controversial.

### **6.4 Japan**

Japanese computer firms found many of their earlier competencies greatly devalued by computer systems and networks. Large systems development based on large Japanese-sourced

computers and with one-off software development for individual sites, however well done, was vulnerable to competitive pressure from much more widely sold hardware and system software platforms and more flexible development environments. A Japan-only PC standard began to look much less attractive as worldwide PC standard bundles started to advance rapidly. While some firms prospered in specific markets (Toshiba in laptop computers, Canon in printer engines, etc.), the traditional giants had great difficulties. Mitsubishi exited the mainframe business. Fujitsu sought to invest in multimedia, often through overseas subsidiaries, and became a Sun reseller. NEC saw declining shares even in the Japanese PC market, and considered conforming itself to the worldwide standard.

## **7. Conclusions**

The analysis of the long term evolution of the computer industry in the three major advanced areas (United States, Europe, and Japan) has highlighted several general points.

First, until the 1990's, competitive technical change was not a destroyer of competencies, but demand opening and competence widening. Second, each industry dynamics had a separate coevolutionary process and was characterized by a different model of the firm. Third, the United States, Europe, and Japan exhibited different forms of supply, due to competitive, institutional and other country-specific features. Fourth, despite separate coevolutionary processes, shifting sources and locations of comparative advantages, American world leadership persisted. Finally public policy differed according to the country and the market segment. All these points will be discussed more in detail in the next pages.

### **7.1 Competitive technical change was not competence destroying, but demand opening and competence widening**

A look at the role of technological change in the overall evolution of the computer industry shows that, until the recent competitive convergence of mainframes with networked computing, competitive technical change has only rarely destroyed the competencies of the main established leaders. In the early mainframe period, entry came mainly from established electronics and office equipment producers. The founding of new demand segments, such as mini and micro, did not destroy the existing capabilities of established mainframe producers. Rather, it was *demand opening and competence widening*: it opened new demand segments with different types of customers and a different user-producer relationship.

Later on, however, competitive convergence meant a convergence on the same type of demand and competence destroying technical change. In fact, the emergence of competitive networked computers using client/server architectures challenged the large-systems competencies of established firms (for a more detailed discussion, see Bresnahan and Greenstein (1995)).

Within each segment, technological competencies were routinely destroyed by the technological and market leader. IBM continually advanced mainframes, and DEC minis, in ways that devalued not only specific old machines but the technical basis of whole product families. In the PC market, Intel and Microsoft routinely made own strategic competence destroying investments, as did Apple.

## **7.2 Each industry dynamic had a separate coevolutionary process**

In each of the three coevolutionary processes, a new technology and demand have brought entrants into the industry thus affecting industry structure. Entrants have in turn introduced innovations, modifications, and changes to the original technology. By opening up a new demand (new types of users), the new technology has created new user-producer relationships and has affected firms=competencies, strategies, and organization.

However, in each specific market segment a distinct coevolutionary process took place. In *mainframes*, coevolution has been characterized by rapid technological change in favor of processing power and data flow speed. Large systems required user-producer relationships, the centralized organization of users=information systems and extensive sales and services efforts by large vendors. Internal finance supported the activities of the large established firms. Market structure was concentrated and suppliers were vertically integrated. A dominant design (IBM/360) emerged in the growth phase of the segment and a market leader (IBM) dominated the industry early on, with a coordinating role over the whole platform and an ability to steer the direction of technical change. The role of universities was relevant as a seeding role only in the early period, and declined later on. U.S. government policy played a role in early support for technological exploration and as a major buyer of early computers. Then, as governments in other countries did, it later opposed the market leader by antitrust policy or anti-IBM procurement.

In *minicomputers* and *microcomputers*, coevolution has been characterized by a type of technological change which developed dedicated application systems in minicomputers or systems with an increased ease of use and lower price-performance ratio in the case of microcomputers. The relationship with customers required much less post-sales efforts, maintenance, and service, because

either the user was already technically advanced (minicomputers) or because the system was easy to use (microcomputers). The structure of the market has been characterized by high entry early on and then by increasing concentration in platforms both in minicomputers and microcomputers. A major difference existed, however, between the mini and micro segments. Niche leaders emerged in specific dedicated applications for minicomputers, while the main microcomputer platforms have been general purpose with competitive supply of commodity hardware. Concentration emerged at the key component level-operating system. Venture capital has played a major role in affecting firms' entry and growth. In this coevolutionary process, the form of government policies (so important in mainframes) did not play a major role, while more general policies favoring education and skill development helped microcomputer diffusion.

Finally, in *computer networks*, a stable market structure has not yet emerged at this writing. Connectivity and compatibility have led to modular, open, and multi-firms client/server platforms. Technical change is following a variety of directions with an upsurge in the number of potential technologies associated with the relevant platforms. In this situation, interdependencies and network externalities have increased. The structure of the industry has thus been characterized by highly heterogeneous firms in terms of size and specialization, active in various platform components, and connected by standard interfaces to firms in other segments. Firms have a wide variety of mechanisms for commercializing their products. There is widespread speculation that one or a few of the firms controlling key interfaces for connecting modular products will come to dominate networked computing, but no single firm has so far been able to govern change and coordinate platform standards. Public policy again plays a role limited to infrastructure and skills.<sup>46</sup>

### **7.3 The appropriate model of the firm was different in each coevolution**

In each coevolutionary process, a different appropriate model of the firm emerged, with its own competencies, organization and strategy (Bresnahan-Greenstein (1995)). *Mainframes* were produced and integrated by the same firm and used in a centralized organization by the MIS department. In this context, a Chandlerian integrated firm became quite successful. This firm was active in the development, manufacturing, marketing and distribution of large systems, and produced some of the components in-house. Market success was related to major and continuous R&D efforts and the three pronged investments in management, production, and marketing. User-producer relationships

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<sup>46</sup> Antitrust actions against potential dominant firm Microsoft have been toothless.

were relevant in establishing competitive advantages, because computer firms supplied systems that solved users' problems, had close interactions with the MIS department of large users, and offered assistance and post-sales services. Large integrated firms controlled and coordinated system development, even in the presence of modularity, because they could control key interfaces. Compatibility across products and over subsequent product families allowed the persistence of existing standards and lock-in of the existing customer base. In *minicomputers*, firms spent less on sales, marketing, and support. Systems were characterized by simple programmable processors and were used for specific tasks, while end users (engineers, scientists, technicians) were technically sophisticated, in most cases developing their own applications. In addition, there was no need to develop compatibility across systems for different uses (much less between minicomputers and mainframes.) In *microcomputers*, firms specialized in components which were part of the platform competed with other specialized firms and did not control buyers' acceptance of the platform nor of the standard. In fact, microcomputer platforms involved several disintegrated firms developing parts of the platform connected by interface standards. Even the IBM PC platform became the IBM/Microsoft/Intel platform, in which innovation was decentralized. Control over the direction of technical progress of the platform by a single firm became very difficult (even by IBM, the sponsoring firm (Bresnahan-Greenstein (1995))). Distribution took place through retail outlets and other decentralized distribution channels.

With divided technical leadership, the potential competition among component suppliers reinforces existing standards. Flexibility in design is limited because unilateral changes by specific component vendors have to be compatible with the standard. Changing component standards is quite difficult because it requires the coordination of several firms. These features of microcomputers continued in the *computer network* period, where modularity and connectedness have increased. Local developments and local feedbacks. This favored the vertically disintegrated firm active in components and parts of the platform, and contributed to the slow emergence of a dominant platform for client/server computing in the present.

As a consequence, the decline of the centralized vertically integrated large firm in the 1990s is not due to a decline in competencies. Rather, it is due to changing market conditions, from a single firm platform to a multi firm platform, with no single firm able to coordinate efforts and compatibility within the platform (Bresnahan-Greenstein (1995)).

Within the evolution of each market segment, there has been a partial convergence to a single firm organizational model, punctuated by the introduction of competing organizational models which

slowed convergence. For example, in mainframes after the rise of IBM to world leadership, Amdahl, Hitachi, and Fujitsu developed a successful imitation strategy. In PCs, after Apple and IBM became industry leaders, there were both clones and entrepreneurial branded PC firms, such as Compaq. Please note also that these new strategies were successful because they matched firms' capabilities with demand, technological and competitive conditions. In some cases, similar strategies were introduced by other firms but came "too early." In mainframes, RCA attempted earlier the same strategy as Amdahl but failed. HP and AT&T anticipated Compaq, but did not have great success.

#### **7.4 Countries exhibited different forms of supply**

During each industry dynamic in each major geographical area, the form of supply was greatly affected by competitive, institutional, and other country specific features. Contrary to the United States, evolution of the *Europe* on mainframe computer industry has been highly influenced by public policy protecting national champions, therefore limiting the exit of unsuccessful producers and perpetuating a concentrated market structure characterized by a national champion and by IBM. In Europe, mini-micro computer industrial evolution has been characterized by limited entry of new producers and lack of venture capital, with American entrants dominating the European market and a few established mainframe producers competing unsuccessfully with them. Finally, in the convergence of mainframes and client/servers, the lack of advanced competitiveness (together with limited entry) in most of computer components impeded the workings of local network externalities and interdependencies, thus generating a market structure again dominated by American firms. In *Japan*, the evolution of the computer industry has always been characterized by a market structure in which few large vertically integrated Japanese computer firms have entered and dominated each of the new segments, and by a public policy that has supported some competition among Japanese producers together with research cooperative efforts at the technological frontier.

**7.5 American world leadership persisted despite shifting sources and locations of comparative advantages.**

The striking feature of the computer industry is that despite of technological discontinuities and three different industrial dynamic, countries=international advantages and disadvantages persisted over long time. Over four decades, the United States has always been at the technological frontier and the world commercial leader. However, the United States has shifted its competitive advantages over time, while other countries were not able to match these advantages. What is at the base of this persistent technological and competitive leadership?

Some factors favoring American competitiveness *persisted over time*. First, the large size and rapid growth of the American market has been unmatched elsewhere. Rapid growth is related to rapid diffusion of new types of computers in the appropriate population of adopters. This is also related to education in computer technologies and a highly skilled labor force in information technology. Second, venture capital facilitated the entry of new innovative firms and the funding of a variety of new initiatives in the United States, in mini, micro as well as in workstations and computer networks. Finally, U.S. universities have always been a source of entrepreneurship and have been highly receptive to the launching of new scientific fields and academic curricula.

Other sources of American competitive advantages have been *changing over time*. In *mainframes*, the major sources of American advantages were linked *to a single firm's advantages*: IBM presented a unique commitment to R&D policies and to the Chandlerian three pronged investments in management, production, and marketing. No other firm in the world has been able to match IBM's capabilities and investments. In *mini and micro computers*, U.S. advantages were related to the favorable entry and growth conditions for new firms in new market segments and in the creation of open multi-firm platforms that created local knowledge externalities. In *computer networks*, U.S. advantages were related to the presence of local knowledge externalities and strong complementarities between various components of the open multi-firm standard platform.

Some of these advantages were *transmitted from segment to segment*. For example, the success of venture capital in supporting minicomputers (as well as microelectronics ventures) led to the availability of abundant venture capital in microcomputers and computer networks. Moreover, some of the entrepreneurs spurring entry in microcomputers and later on in computer networks came from established firms active in minicomputers first and microcomputers later.

The geographic location of the competencies supporting American success has several times shifted within that large country. In mainframes, American advantages were related to the areas of IBM location of R&D and production, centered in New York but widely dispersed. For minicomputers, the sources of competitive advantages were mainly centered with the Eastern part

of the United States, with important exceptions like western entrant Hewlett Packard. In microcomputing and even more so in computer networks, we have seen a regional shift from areas in the Eastern part of the United States (such as Route 128) to the Central and Western part of the United States (such as Silicon Valley). This implies the need to carefully consider the unit of analysis of competitive advantages: the division/department, the firm, the region, or the country (See Saxenian (1994) for more detail).

### **7.6 Universities played specific roles during the history of the industry**

Universities played two roles in the computer industry. First, very early in the industry, they were generators of scientific knowledge and prototypes in several advanced countries. At the beginning of the industry, universities were the locus of the first big university-led projects and relevant sources of scientific as well as technological knowledge. Second, in the United States they played a role as sources of scientific knowledge and entrepreneurship in minicomputers and microcomputers. The role of MIT for innovation and entrepreneurship in minicomputers, and Stanford and the University of Texas for microcomputers and workstations has been relevant. Only Cambridge in the UK has played a similar (albeit more reduced) role in Europe.

### **7.7 Public policy differed according to the country and the market segment**

In *mainframes*, public policy has been of a *top-down, mission-oriented type*. It has been quite different in the United States, Europe, and Japan. Early American military policies (and to a lesser extent the UK) have been successful in the support for early exploration and in opening windows to different technological alternatives. In addition, nonmilitary procurement fostered competition through procurement from multiple sources. As we have documented earlier, the American military and government pursued goals driven by military-government needs, but also helped the technological and commercial development of the industry. As we have shown in this paper, however, these policies were not at the base of the success of IBM. In *Europe*, there has been a major involvement of the various governments for the support for national champions in an attempt to create strong competitors to IBM. These policies (research subsidies and public procurement) were not successful, because they did not foster competition in the domestic market and were protective of a single (laggard) firm. Moreover at the time of their launch, IBM was already in a dominant position in the various European countries and the national champions had already accumulated technological and commercial lags. De facto these policies created a barrier to exit for unsuccessful producers. In *Japan*, on the other hand, public policy has been successful in the catching up process with IBM,



because (contrary to the European experience) it nurtured multiple competitors, coordinated imitation of IBM through coerced licensing, and sponsored collaborative research. As we have seen, the failure of Japanese policy has been related to a market shift, not to the policy as such.

Please note that *antitrust policy* played two different roles. First, it played an anti-IBM role both in the United States and in Europe. In the United States, IBM had to unbundle mainframe hardware from software and was forced to handle Amdahl and the PCMs more gently. In Europe, antitrust policies have been very attentive to IBM as well. Second, antitrust policy had a competition increasing role only in the United States. In fact, in Europe it was highly tolerant of the domestic national champions

On the contrary, in *microcomputers and computers networks*, public policy has been focused mainly on *infrastructure, education, and standard*. Direct or indirect support for the creation of favorable conditions, such as an advanced infrastructure, the creation of skills, and so on, has proved quite successful in enlarging the size and fostering the growth of the market, increasing communication and interaction and assisting entrepreneurship. (Malerba (1992))

Two final comments on policy refer to the dynamic setting in which these policies are launched and take place. First, the discussion of the computer industry clearly shows us that public policy has to be "adapted" and tuned to the specific stage and market segment that has been selected for intervention. For example, apart from their relative success or failures in various countries government policies for mainframes could not be used for minis, microcomputers, or computer networks. Second, imitation policies aim at a moving target. Think of catching up policies. In situations of rapid technical change, catching up policies should not focus only on the established world leader and the winning technology. The policy target itself may be displaced by a new world leader or by a shift in the relevant technology or market. This is the case of the successful catching up by Japan in mainframes during the 1980s, which, however, was confronted by a major shift in technology and market at the moment of the catching up. In this sense, public policies should be flexible and sensitive, and keep open windows on a wide range of technologies and market developments.

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