

Technological Competition and the Structure of the Computer Industry

by

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I. INTRODUCTION

Computer industry structure changed dramatically in the 1990s after a long period of stability. Early in the history of the industry, a concentrated industry structure arose and persisted in mainframe computers. The same dominant firm, IBM, served the same customers for decades. Nonetheless, technical progress opened many commercial opportunities. There was substantial new entry into the computer industry, but not into direct competition with the established leader. Instead, entrants opened up new market segments, like minicomputers or microcomputers. Then the early 1990s saw a “competitive crash” in computing. Firms that previously supplied different segments now compete for the same customers. This internal entry or mobility has, at last, destroyed existing seller rents in several segments. The much more aggressive behavior of entrants has led to a more competitive market structure.

The goal of this paper is to understand both the long continuity and the recent change within the same analytical framework. We look at the overall computer industry and its segments in distinct but linked parts of the analysis. For the segments, the relevant issues are ones of concentration and persistence in market structure. For overall industry equilibrium, we ask a more difficult question about changes over time in entry behavior. What led entrants to flee competition with established firms in one era while challenging them later on? To analyze what changed and why, we characterize both the overall industry equilibrium and strategic behavior within each segment. We will hold ourselves to an evidentiary standard that is broad rather than deep. We will provide an explanation, but not detailed analysis, of all the main industry structure features.

The first force behind computer industry structure is rapid and sustained technical progress. Each year, integrated circuits and other electronic components become better, faster, and cheaper, providing opportunities to improve existing computers as well as to design new kinds. This feature of supply changes little over time, however, and thus cannot provide, by itself, much of an explanation of changing industry structure. Many (business) observers have further pointed out that supply in the microcomputer segment was organized in a new way, with much more vertical disintegration and specialization than came before. This new way of organizing supply, if it were a new (business) invention superior to what it replaced, could provide an explanation of the newly aggressive internal entry.

One version of this supply story will indeed form part of our explanation of the changing pattern of entry. The proliferation of different kinds of firms and technologies in the overall computer

industry over time meant an increase in the number and type of potential entrants into any particular segment. However, the supply story turns out to be incomplete in three distinct ways. First, demanders in the different segments value different aspects of technology and supply. The distinction between commercial demanders in white collar work and technical demanders in factories and laboratories is particularly important here. These differences slow entry. Second, these same differences permit new segments to act as “incubators” for firms and technologies that, had they entered directly against IBM early on, would have failed. The new form of supply, and its associated technologies, were far from superior at first. These points are critical in understanding the overall computer industry’s changes over time. We weave these ideas together in the concept of indirect entry, analyzed in more detail below. Indirect entry links within-segment equilibrium and industry wide equilibrium by providing a positive analysis of the sources of potential entrants.

There is a third point about demand which bears directly on within segment equilibrium. Adding the demand side does not simply increase the number of forces bearing on market structure but also changes their character. Equilibrium in each segment of the computer industry follows its own logic of concentration and persistence, determined by buyer/seller interactions not technology alone. Interactions between buyers and sellers are organized around computer platforms, such as the IBM System/360 or the Apple Macintosh. Platforms have interchangeable components, so many buyers can share the benefits of the same technical advance. Interchangeable components also permit buyers to use the same platform over time, avoiding losses on long-lived software or training investments. The sharing is a social scale economy: there tend to be few platforms in any segment. The long-lived investments lead to platform persistence, whether for cost-minimizing, coordination-failure, or strategic reasons. Platform concentration and persistence are not the same as a concentrated structure with long-lived dominant firms. Different platforms have been organized and controlled by sellers in different ways. Sometimes, as in mainframe computers, we see a single platform, offered by a single firm with a high level of vertical integration (IBM). In personal computers, the IBM PC platform changed from single firm control to decentralized control by a large number of firms to the “Wintel platform” controlled by Microsoft and Intel. Our analysis of platform persistence and concentration is robust to the exact nature of the struggle for control among sellers.

The advantage of building such a robust analysis is that it lets us be much more careful about what has changed and what has stayed the same in the computer industry. Some of the same forces that were critical in the 1960s, notably the forces leading to a small number of distinct, long-lived

platforms in commercial computing segments, are still in place. What has changed is the nature of competition for control of those platforms. We argue for a view in which both demand forces and supply forces lowered entry barriers for firms, but not platforms. We introduce a new market structure concept, divided technical leadership, i.e., the supply of key platform components by multiple firms. Today, the same firms that compete to control technical standards also make products that work together. We argue that divided technical leadership is inevitable in the current computer industry and that divided technical leadership makes entry easier.

Our analysis links together several distinct arguments over a wide range of history and segments. Accordingly, we build it in stages. Section II has our analysis of the role of the platform. This analysis draws on familiar theory and stays within market segments. Section III looks at the competitor-fleeing behavior of the founders of whole new segments and of internal entrants' mobility from one segment to another, in our first look at the overall industry equilibrium. Section IV examines the factors that might make mobility-entry from one segment into another succeed, even when there is effective competition in the entered segment. In section V, we see how industry-wide conditions favoring mobility-entry improved over time. At that stage, we have all the ingredients in place to understand technological competition in the largest industry in the modern economy, and to explain its changes over time.

II. PLATFORM CONCENTRATION AND PERSISTENCE

We first examine the forces leading to platform concentration and persistence within computer industry segments. In this section, as in later ones, we look closely at a specific historical era before turning to the analytical issues. Specifically, we first examine the IBM System/360. This was not the first commercially important computer, but it was the first platform. It played a central role in the concentrated structure of the mainframe segment from 1964 onwards, and in the persistence of IBM's dominant position. Our emphasis is on the platform as a general mechanism to coordinate buyers' and sellers' efforts, and on the robust implications of this mechanism for market structure in segments. Accordingly, once we have built our within-segment framework, we end this section by looking at market structure in segments with quite different demand and supply characteristics from those in IBM mainframes.

II.1 The Invention of the Platform: the IBM System/360

From the mid-1960s onward, IBM dominated the business mainframe segment with a single computing platform that began as the IBM System/360.¹ It is by now a cliché that IBM was the most successful computer firm in the 1960s because it combined technical and marketing capabilities. We look inside this commonplace remark for analytical lessons about the sources of concentrated structure.

Like many “second generation” computers, the System/360 was more powerful and complete than its predecessors. The System/360 also differed from earlier IBM models by offering operating system compatibility across computers having different CPU speeds and disk sizes. It established plug compatibility for hardware: monitors, tape drives, disk drives, controllers, card-readers, and CPUs. Since the same IBM software worked on all models, application software and databases on one system could be easily moved to another. Critically, IBM invented technical standards for how the products worked together and embedded them in its operating system and new versions of all products. These are the hallmarks of a platform. Compatibility standards meant that the different hardware and software components available in the marketplace (in the early going, available from IBM) worked together. A user program written to the platform standard would work with any of a wide variety of system configurations.

Platform compatibility was valuable to business customers. Computer use involved expensive software and training costs and complex changes to business systems. Service made those easier, and compatibility meant that the value of the investment in software and training would be preserved. Much uncertainty surrounded the business use of computers in the 1960s. It was difficult to forecast the extent to which new applications would expand computer usage. The purchaser of a System/360 model acquired the option to increase capacity without losing their investment. Three features led to IBM’s success: the technical advance inherent in the System/360, a field sales and service force to help users choose and configure IBM systems and applications built on the IBM platform, and the value of the option to increase capacity within the same platform.

¹ For a more complete description of this era and contrasting analysis, see Pugh et al. (1991), Fisher, McGowan and Greenwood (1983), Fisher, McKie and Mancke (1983), Sobel (1981), Fishman (1981), Katz and Phillips (1982), Brock (1975a, 1975b) and Flamm (1987, 1988) among others.

Total investments by IBM and its customers in platform-compatible components were very large.² Those large investments called for responses from competitors if their platforms were to sell well. Some mainframe competitors emulated IBM's strategy and attempted to build their own broadly useful platform. A second group pursued narrow niches where compatibility was less of an issue for users. A third group attempted compatibility with IBM by duplicating IBM designs; the RCA SPECTRA is an example of both the strategy and its limited success. None of these strategies was very effective. Only a few of the niche platforms managed to sell well.³ The resulting market structure became quite concentrated, and the IBM mainframe was the dominant platform.

II.2 A Robust Theory of Dominant Platforms

Powerful forces limit the number of platforms in market equilibrium. A platform is a device for coordinating disparate rapidly moving technologies and for market coordination between buyers and sellers. Platforms have significant scale and scope economies, and significant strategic implications as well. In this section, we introduce a robust, positive theory of concentration in terms of platforms. We emphasize positive theory because a large normative literature has produced more heat than light.⁴ We emphasize robustness because we will reuse the platform concentration theory in a wide variety of computer industry contexts over several decades.

² For IBM, the System/360 involved a very large investment in all the different component technologies and in the service and support capabilities. It also involved a management structure that could coordinate technical decisions across many technologies and product lines, even when this led to a great deal of conflict (see Pugh et al. (1991, Watson Jr. and Petre (1991) and Sobel (1981, 1986) for the conflicts surrounding System/360 and their resolution). IBM's customers' investments were also quite large (e.g., see Inmon, 1985).

³ Burroughs, Univac, NCR, and Honeywell attempted broadly useful platforms in competition with and incompatible with the System/360. Burroughs found willing users for their architecture with innovative memory stacking. NCR's small systems were quite successful in some banking applications and especially in retailing. Honeywell and Univac found willing buyers in the federal government, particularly in the military. Honeywell successfully marketed their systems for use in communications and in large process control problems, such as running air conditioning with a large building. CDC marketed in the niche for high-performance number-crunching computers in scientific and engineering applications. See e.g., Fisher, McKie and Mancke (1983), Katz and Phillips (1982) and Flamm [1987].

⁴ Different authors took contrasting sides of the *U.S. vs. IBM* antitrust case case, seeing IBM as either a brilliant creator or a defender of monopoly. They see IBM's invention of the platform either as valuable use of scale and scope economies or as barriers to entry, and see IBM's customers either as well supported or as locked in. For contrasting analysis and characterizations see, e.g., Brock (1974), Fisher et. al. (1983), and DeLamater (1986).

We use John Sutton's (1991) synthesis of the strategic theory of concentrated industry structure. The main advantage of the synthesis is that it establishes robust conditions for concentration. "Robust" here means not depending on difficult-to-verify strategic interactions, such as the erection of strategic entry barriers, first-mover advantages, etc. .

Sutton's main result is simple to state. Industries in which there are endogenous sunk costs (ESC) will have a concentrated structure even if there is a great deal of demand. This pattern does not depend on how sellers interact strategically.⁵ The key to the analysis is the definition of endogenous sunk costs. These are expenditures undertaken by sellers to improve their products for users. (In Sutton's empirical analysis they are typically advertising and other brand-enhancing expenditures in consumer goods industries.). Expenditures are ESC under four assumptions:

- (1) ESC must be sunk (irreversible).
- (2) A single firm spending more on ESC raises buyers' valuation of only that firm's products.
- (3) There must be no practical bound to the size of the ESC. At any level of expenditures, it must be possible to spend more to attract customers.
- (4) A large fraction of potential customers must respond to the ESC.

Sutton compellingly argues that fragmented industry structure is impossible in the presence of ESC. If the industry structure were fragmented, a firm could invest in ESC, drawing many customers to itself. Accordingly, firms who do not invest in ESC can expect to be reduced to secondary market positions. In general, when ESC are important markets will only sustain at most a few firms in equilibrium. The synthesis does not need to specify the precise links between competitive outcomes and the strategies of sellers, e.g., whether the first mover will have an advantage, etc. A very important result is that, under ESC, market demand growth does not lead to fragmentation. A larger market will have higher ESC instead of more firms in equilibrium.

To use this theory in the computer industry we need to apply it to platforms instead of firms. As we will see in a moment, the assumptions of the theory about demand are satisfied for business computing as long as we are talking about platforms, not firms' product lines. The distinction matters, as we shall see, for the case of platforms supplied by more than one firm.

⁵ For a much more careful statement of these and the following results, see Sutton (1991).

We saw that assumptions (1) and (3) were true for mainframe computing. Sellers' development and coordinating costs are clearly sunk. Buyers' also sink costs into building their parts of a platform, including in-house software and training. Much of the cost of building buyer/seller communications relationships through a field sales force is also sunk. The value of these investments is effectively unbounded. Users of computers can benefit at a variety of expensive margins. The value of computers to users increases where there is more rapid technical progress in individual components, a wider span of compatibility across components of different sizes or speeds, or improved features. Users of mainframes, as of other business computers, have managed to absorb very expensive versions of each of these kinds of improvements.

To make assumption (2) true in computing, we clearly must change from "firm" to "platform." Expenditures to make a platform better raise the demand for components of the platform regardless of seller. It happens that IBM sold almost all of the components of the System/360 platform. Yet if RCA had succeeded in its strategy of making System/360 clones, their and IBM's inventions and investments would have raised the demand for the entire platform, not just for their own products.

The possibility of multifirm supply within a specific platform does not undercut the theoretical observation that there will be few platforms. If the firms invest in developing the same compatible platform, individual firms' ESC tend to reinforce one another by expanding demand. This will tend to make a segment have few platforms even if it has many supplying firms. Of course, if each firm pursues its own platform strategy, we are back in the world covered directly by the Sutton theory. Either way, equilibrium will be concentrated in platforms. While unimportant in 1960s mainframes, this observation about multifirm supply becomes quite important later in the history of the industry.

Assumption (4), about customer unanimity or near-unanimity, tells us to what segments of the computer industry the theory applies. Our argument that all 1960s business users of computers valued the same ESC depended on the details of their technical and economic circumstances. Other kinds of users would not necessarily value the compatibility option as highly, and the tendency to concentration would be correspondingly less.

We can learn two general lessons about computer industry structure. First, an ESC industry arose in computing after the invention of the platform. Strong ESC forces for concentration in platforms (not necessarily in firms) were unleashed. The second general lesson is

closely related but frequently overlooked. The creation of a platform is not merely an engineering feat. The creation of a platform shapes market relationships between buyers and sellers of computers. In turn, those market relationships shape market structure.

II.3 Persistence and the IBM System/370

The 1970s saw continued high concentration in the mainframe segment with IBM continuing as the dominant firm.⁶ Users migrated from the System/360 to the backward-compatible and much more capable System/370. IBM needed to undertake very substantial new technical investments to design a backward compatible upgrade with more capabilities. Users, however, did not need to abandon much of their sunk platform-specific investments. What are the implications of this kind of coordinated migration to a new, but still compatible, version of a platform?

In the late 1960s and early 1970s, technical advance opened opportunities for designing new components in computing. Some newer mainframe platforms began to offer features, such as timesharing, that the System/360 lacked. Since the System/360 had not been designed with those features in mind, it would be quite expensive to add them, a dilemma for IBM.

IBM's solution was to manage a coordinated move forward. The timesharing System/370 offered backward compatibility with the System/360; much of the same software, peripherals, and programmer knowledge were still useful. This preserved a System/360 user's investments while incorporating many new technical innovations. Backward compatibility permitted users to employ many of their existing assets on the new system since training, programs, and some peripherals did not need to be repurchased with the new system. In addition, installing the new system was quick, minimizing the costs of operating dual systems as well as other transitional expenses.⁷ This was important if the user had invested in many valuable applications, such as databases, which were not easily portable across platforms. By the early 1970s, most large business users had experience with the System/360, so backward compatibility was widely valued.

The move forward involved two difficulties. First, IBM needed to make expensive design changes to incorporate cutting-edge technical features like time sharing into a backward compatible system. IBM invested heavily in new technology, both hardware and software,

⁶ For a much more complete history, see Fisher, McKie and Mancke (1983), Pugh et al. (1991), Flamm (1987, 1988), Phister (1979), and Sobel (1986).

⁷ See Greenstein (1997 forthcoming) for analysis of these costs at the technical and organizational level.

abandoning most of the specific technical advances that underlay the earlier System/360. Second, outside firms made many hardware and software components compatible with the evolving platform. Many “plug-compatible” peripheral firms making disk and tape drives, among others, had grown up. IBM could have chosen many different approaches to this incipient vertical disintegration. In fact, IBM chose to maintain firm control of the System/370 standard with an aggressive response. As a result, control of the direction of the platform and its standards remained completely centralized.

This strategy left in place many important elements of firm and industry equilibrium. IBM’s customer relations continued on the same basis. IBM did not alter their internal management structure for servicing and marketing new products. Nor did the new products alter the organization’s emphasis on the relative importance of customer-oriented features of IBM’s services and product designs. IBM continued to be the largest firm by far, and the System/370 platform continued to be dominant as well. As further reinforcement, there was ongoing exit of mainframe manufacturers who were giving up the competition with IBM.⁸

We do not wish to dwell too long on the history of the mainframe market segment. We note, however, that IBM managed several coordinated migrations through the 1970s and 1980s. Two difficulties grew steadily worse. More technical opportunity sprung up outside the IBM mainframe platform’s ambit and needed to be incorporated in a backward compatible way. User groups, trained system engineers and operators, programmers, sales and service personnel inside and outside IBM, all had a stake in these decisions, constraining upward compatible choices. The vertical disintegration of the platform’s production continued as well. After a time, many peripherals, much software and service, and even the computer hardware could be obtained from others, not solely from IBM.

Though IBM’s tactics changed over time, IBM maintained firm control over the platform. IBM determined, by setting technical standards, what could be connected to an IBM-compatible system. IBM’s connections with its customers and its ownership of some key elements of the platform, like operating systems, left it in this position of control. The inventive efforts of other participants in the platform, like customers, user groups, and third-party providers of compatible

⁸ Most notably, GE and RCA invested heavily and exited after substantial losses (See Fisher et al. (1983)). Overseas, government sponsored firms also failed, with only a few exceptions (see Bresnahan and Malerba (1997)).

components, made the platform better. This was to all participants' advantage but notably to IBM's.

II.4 The Economics of Persistence

A large body of theory has emerged to explain the persistence of *de facto* standards, like those at the heart of computer platforms. A central idea of this theory is positive feedback among the different components associated with a platform.⁹ In this section, we consider the applicability of this theory to the computer industry.

This theory, too, is about markets as much as it is about technical change. It makes a variety of assumptions about buyers' and sellers' behavior. These assumptions are consistent with, but also more detailed than, those of the ESC theory. These are:

- (1) Buyers and sellers of technology make platform-specific investments. Different sellers may advance different components. An interface standard determines when components are compatible members of the same platform.
- (2) At least some of the platform-specific investments are long-lived and influence the costs and benefits of technical and market decisions made over time.

Mutually reinforcing behavior arises when standards coordinate behavior in a static sense, and when standards coordinate investment activity over time. Buyers, sellers, designers, or third-party software vendors make long-lived platform-specific investments, which tends to keep platforms in operation for long periods. For example, in this theory IBM did not have to introduce the advances of the System/370 technology ahead of its rivals. Equilibrium technical change involved backward compatible timesharing soon enough so that the vast majority of System/360 users did not switch to a competing platform.

This theory of standards persistence has implications for the origins and demise of platforms. Just as platform standards are hard to stop, they are hard to start. A platform needs a "critical mass" of adopters and a critical mass of complementary software (and sometimes other components). "Positive feedback" underlies survival of existing standards and "getting over a hump" of acceptance for new standards. If a new standard does get "over the hump" then positive feedback quickly favors it. Getting over that hump, however, may not necessarily come easily or quickly.

⁹ This is also known as the theory of interface standards. See Besen and Saloner (1989), David and Greenstein (1990), David and Steinmueller (1994) and Besen and Farrell (1994) for more careful and complete statements.

Related literature debates the normative implications of a third assumption, one with a strong “coordination failure” aspect. This is:

(3) In the uncertain environment of new technology, it may be difficult to coordinate platform-specific investments.

Stated broadly, (3) is plausible. Yet there are many variations. Theories differ in exactly which agents have difficulty coordinating which decisions. Each type of assumption leads to very different normative conclusions about persistence. Sellers’ role in persistence is variously interpreted as efficient coordination or exploitative preservation of a monopoly position. Our positive goals lead us to use (1) and (2) only. We make no use of any variant of (3) nor of any normative implications.¹⁰

II.5 A Less Concentrated Segment Illuminates the Theory: Minicomputers

Not all computer segments have the same demand characteristics. As demanders valuation of platform compatibility falls, ESC forces become less important and so do the forces for persistence. We illustrate this by introducing the minicomputer segment and contrasting it with mainframes. Minicomputer market structure in the 1960s and 1970s was consistently less concentrated than mainframes. While DEC was the largest market share firm, there was successful entry.

At their invention in the late 1950s and early 1960s, minicomputers had a technical customer base. An engineer or scientist wanted a communications controller, instrument controller, large-system pre-processor, real-time data acquisition processor, or scientific or engineering calculator. In many of these applications, an engineer did not require a compatible family of systems since the processor was used repeatedly for the same task. In addition, technically sophisticated users did not require frequent servicing from the vendor to help them operate a system.¹¹

¹⁰ IBM’s management of the migration from the System/360 to the 370 can be interpreted in two ways. It either results from barriers to entry erected by IBM or it reflects the efficient preservation of users’ investments in the platform (Fisher et al., (1983), Brock, (1975a, 1975b)). The debate over the social efficiency of the technological lock-in to standards, such as the QWERTY keyboard, has a similar dichotomy. QWERTY can be interpreted either as a socially inefficient lock-in or as a rational preservation of durable investments with little foregone opportunity costs (David, (1985), Liebowitz and Margolis, (1995)). These normative issues also arise in the discussion of Microsoft’s behavior. Microsoft either integrates technology for the good of all customers or it sabotages innovation from competitive software firms through its control of an essential facility (Reback et al. (1994) or FTC (1996)). Resolution of any or all of these normative debates is a distant but worthy research goal.

¹¹ See Bell and Mudge (1991), Dorfman (1987), Fishman (1981), Packard (1995), and Pearson (1992).

Correspondingly, the nature of commercial relationships between buyers and sellers was different from in mainframes. Minicomputer manufacturers did not have large field sales forces and support people in their customers' facilities. Sometimes the customer did not even know who made their minicomputer, as when a "value-added manufacturer" embedded the processor in a product and sold it under its own name. Some early minicomputer manufacturers, such as DEC and Hewlett-Packard, did not even initially claim to make computers -- that would mean they were competing with IBM. They made "controllers" or "instruments," which happened to have simple programmable processors in them. Accordingly, the systems for dedicated applications were also cheaper, as sellers avoided the elaborate and costly distribution activities.

Technical users put a lower value on compatibility and on service and support (because they often could just do it themselves for much cheaper), than did business users. This had two important implications. One impact was that there was a segment boundary between minicomputers and mainframes, as technical and business users had diverse demands.¹² Segment boundaries can be difficult to define in an industry where the product is a general purpose device. We use a definition of segments that turns on distinctions across customers in terms of technological needs and service and support needs. This definition meant, importantly, that the minicomputer firms were sheltered from the most obvious and direct form of competition from IBM. It would have been very difficult for IBM to extend the reach of the System/360 or /370 platform to dominate the minicomputer segment given minicomputer users' distinct character from business users of mainframes.

Another impact was that there were less concentration and persistence in minicomputers. DEC's PDP-8 family was the most popular system but entrants such as HP, Data General, and many others gained market share nonetheless. These differences between mainframe and minicomputer segment market structure reflected market as well as technical forces.

II.6 Dominant Platforms Persist Even Without Dominant Firms: Microcomputers.

Our predictions about platform concentration and platform persistence do not depend on any theory of firm conduct, such as strategic foresight or monopolization. We can see this point in

¹² It would have been very difficult for IBM to extend the reach of the System/360 or /370 platform to dominate the minicomputer as well. Technical and business demand called for very distinct supplying industries. These arose from difference in software application needs, as well as service and support needs.

the microcomputer segment twice, before and after the introduction of the IBM PC.¹³

In the microcomputer segment of the late 1970s and early 1980s, the platform with largest market-share used the CP/M operating system and (usually) the S-100 bus architecture. No single computer maker controlled the interface standards, operating system, or hardware architecture. Scores of firms made CP/M machines. Software for this platform was (mostly) able to run on the computers from any of these firms. Customers could mix and match hardware, software, and peripherals from several sellers. The second-most common platform was the Apple II, which was sponsored by a single firm. The other platforms with single sponsors, such as the TRS from Tandy, were not important competitors, as Apple and CP/M machines dominated the early market. Interestingly, both platforms relied on arms-length market institutions instead of bilateral relationships with customers. Their point of contact was a retail store or a mail-order house, not a field sales representative.

The lack of a sponsor for one of the leading platforms illustrates that the ESC theory of platform concentration is robust to the number of firms that supply a platform. No single agent took responsibility for coordinating technical change of the various CP/M platform components. Instead, an anarchic rabble of firms each advanced one or more components.¹⁴ Their efforts, loosely coordinated by market forces, led to a market with only a few platforms though many firms in equilibrium.¹⁵ The robust logic of the ESC theory requires only this: a fragmented industry structure leads to probes that break the structure down. Attempts to coordinate multiple technologies by multiple firms can, given positive feedback, be such a probe.

A theory of industry structure that is robust to the exact workings of strategy has a new advantage here. We do not need to assume that multifirm supply is the same as coordinated supply. Indeed, it is clear that the CP/M rabble did not behave exactly the same as a platform

¹³ The history is well known. See, e.g, Freiburger and Swaine (1984), Langlois and Robertson (1995), Ferguson and Morris (1993), Cringely (1992), Chopsky and Leonsis (1988), and Steffens (1994).

¹⁴ The lack of a sponsor created some coordination failures. There was a universally recognized 8-inch disk format for CP/M. The move to 5.25-inch disks saw a wide variety of distinct disk formats. Customers could buy any CP/M software for their computer, but had to specify exactly what kind of computer it would be on so that they could get the right disk.

¹⁵ See, Farrell, Monroe and Saloner (1994) for analysis of the strengths and weaknesses of this form against a vertically integrated organization.

sponsor would have. It made more mistakes of coordination.¹⁶ It may also have moved forward more rapidly by making piecemeal technical progress in components rather than waiting for a coordinated solution. It appears that speed is the benefit and coordination failure the cost of unsponsored platforms, or of multi-firm supply more generally.

The early dominant platforms did not persist, as platforms did in the mainframe world. Both CP/M and the Apple II were eclipsed after a major technological dislocation, e.g., the transition to “16 bit” from “8 bit” micro-computing. We return to the dislocation and to the limits to platform persistence in our next section.

The 16-bit era also saw many new platforms proposed, but once again two platforms dominated, the Macintosh and the platform that began as the IBM PC. Both have shown persistence, surviving well over a decade, through a stunning amount of technical progress. The Macintosh is a sponsored platform with a closed hardware architecture. The PC is more complicated. It began as the IBM PC, with IBM as the sponsor and with a vertically disintegrated structure for invention and production of components. Later, the platform became the “industry standard architecture,” an unsponsored structure. Still later, after its operating system was succeeded by the backward-compatible Windows, it became the Wintel (Windows/Intel) standard. Despite all this change, the forces of backward compatibility led to platform persistence.

In microcomputers, the equilibrium supply of platforms is concentrated and existing platforms tend to persist. We see that these outcomes occur because buyers and sellers jointly value compatibility, even when the equilibrium supply of firms is not concentrated and those in which firm persistence is in doubt. The complex and changing sponsorship structure of the PC tells us about the robustness of the positive theory of platform concentration and persistence. Rapid and coordinated technical progress has kept the IBM platform in a dominant position for a decade and a half, which covers many generations of products.

III. ENTRY AND MOBILITY OF PLATFORMS

We now turn from the analysis of the individual segment to the analysis of the overall computer industry. We start by looking at the period in which expanding technical opportunity

¹⁶ Rapid: price performance measures fall by about a fourth each year. Coordinated: the move to 32-bit processors, multi processing operating systems, and graphical user interfaces involved cooperation and competition among many different firms. There are elements of coordination failure too, which we will treat in detail in sections below.

led to the founding of new segments, such as the minicomputer and microcomputer segment, served by new platforms. There are two striking empirical regularities. First, each new platform was introduced by new firms, not by previously successful computer companies. Second, each new platform was first used by technical users in a new segment, far from competition with existing business platforms. Though the creation of these new platforms were technically impressive innovations, in general these events did not disrupt the market structure associated with established platforms in established market segments.

The fundamental background fact for the competitor-fleeing behavior of entrants must be related to concentration and persistence within segments. We add another element, however, which is time-to-build for platforms. The complex and complementary nature of components in a computer platform means that it can take time for a new platform to work well for its users. As a result, a newly invented platform will be a weak competitor for established platforms. This weakness leads entrepreneurs making new platforms to flee competition, pursuing new areas of demand. We first examine cases where successful entrepreneurs acted in exactly this way. We then examine some important examples of entry behavior which was somewhat more aggressive toward existing firms and platforms, and show that the difference is well explained by the same analysis.

III.1 Founding of New Platforms Flees Competition: Minicomputers.

We examined the structure of the minicomputer segment in the last section. Let us now consider its founding. Entrants who supplied technical users avoided competition with existing mainframe platforms. Established platforms were difficult to dislodge due to the strong ESC and backward-compatibility forces in business computing. Business computing platforms simply need expensive marketing campaigns and distribution activities. It is also cheaper to enter, i.e, to start a new platform, in the technical arena because these users demand less servicing and fewer support products. These two forces directed entry toward technical segments.

These forces can be seen by revisiting the minicomputer segment, this time considering the forces that led to avoiding competition with the IBM 360/370 and the creation of a separate segment. Early minicomputer manufacturers recognized avoidance of competition with IBM in explaining their own success. By serving technical users and by avoiding complex field sales and support costs, minicomputer vendors deliberately (1) avoided competition with, and (2)

proceeded more cheaply than, IBM.¹⁷

The historical record will not support an argument that early minicomputer firms understood this strategic argument *ex ante* and deliberately avoided IBM. A wide variety of different firms and platforms were founded in the industry's early period. It is probably a better theory that industry equilibrium selected those firms, like DEC, that used cost- and competition-avoiding strategies.¹⁸ By the early 1970s, however, competition-avoiding was much more deliberate. For example, when Hewlett-Packard entered into the technical minicomputer business, its executives were cognizant of the costs of competing for customers who wanted business applications. HP, the instrument company, already had good relationships with technical customers. They also anticipated and avoided formidable competition from established mainframe providers.¹⁹

Minicomputers formed a separate segment than mainframes, serving widely different customers. There was rapid development of hardware, software, and networking gear for minicomputer platforms, separate from and parallel to mainframe developments. Entrants' cost-avoidance and competition-avoidance accentuated the differences between the segments.

III.2 Competition-Avoidance and Segment Founding in Microcomputing

Technical progress in electronics expanded technological opportunity, both in the computer industry itself and upstream in markets for integrated circuits or memory devices. Two new segments built around small-sized CPUs and independent individual computing, microcomputers and workstations, were based on an important technical advance, the microprocessor. Still, their foundings were competition-fleeing.

Early microcomputer platforms, founded in the mid-1970s, avoided competition by a new mechanism. The new segment initially was defined by the combination of the size and speed of the central processor customers with the type of buyer, individual "hobbyists," i.e., people who could program their own computer and even assemble it. Competition with minicomputer platforms

¹⁷ See Pearson (1992), particularly chapters 4-6, for a recounting of these strategies.

¹⁸ Equilibrium selection among a variety of different types of firm is a theme found throughout evolutionary economics. See, generally, Nelson and Winter (1982), Gort and Klepper (1982), Utterback (1994), and on computers, Langlois and Robertson (1995).

¹⁹ See Packard (1995), chapter 7. At the expense of considerable internal dissension, Hewlett-Packard canceled the development of new products that required more elaborate servicing and marketing than they already had in place (pp. 103-104).

was avoided because microcomputers were far smaller and cheaper than minis. The costs of complex distribution and support structures were also avoided. Diffusion and sales of these platforms depended on the sharing of technical information in a hobbyist community. The period was one of very rapid technical progress but not one of professionalized marketing efforts.²⁰

Workstations, whose sales began to grow rapidly in the mid 1980s (after many precursors arose in the minicomputer industry of the 1970s), reflect a different pattern of cost- and competition-avoidance.²¹ They were developed and sold by entrepreneurial firms, with service and support similar to minis. They were suitable for technical users, particularly engineers with numerically intensive problems. They avoided competition with minis by being marketed as complementary goods. The “diskless workstation” would serve an individual engineer, perhaps a designer. It would be networked to a minicomputer, which would store the engineers’ programs and data on its disks.

In each case, cost-avoiding and competition-avoiding forces were at work, avoiding a direct confrontation with the ESC and standards persistence associated with established platforms. Each time a new kind of computer took advantage of new technological opportunities associated with the newest electronics. A vibrant technically sophisticated community then grew up and supported rapid technical progress within the new platform. The platform avoided substantial marketing costs by selling to technical users and avoiding competition with existing platforms.

III.3. Platform Mobility

We now turn to a distinct kind of segment-founding event, the movement of existing platforms toward new uses. We look at two of these, the creation of the business minicomputer and the office microcomputer. These events involve entry into business computing, where incumbent platforms like the System/370 served most users. As it turned out, these events were still less competitive than the disruptive platform shifts of the 1990s. The entrants ended up serving quite different segments of business computing from those served by the incumbents.

Two observations are important. First, mobility of an existing platform to a new kind of use costs less than the creation of a new, fully capable, platform. Simply put, many of the existing components of the platform can be re-used, redesigned or retrofitted for new applications.

²⁰ See Freiburger and Swaine (1984) for the history from an engineer’s perspective.

²¹ For a wide variety of interpretations see, for example, Steinmueller (1996), Chandler (1997), and Baldwin and Clark (1997).

Second, even with lower costs, when any entrant platform must sell to an existing platform's main customer base, it confronts the forces, i.e., ESC and standards persistence, leading toward persistence of the established platform. This confrontation can be resolved in a variety of ways and no single factor dominates in general. Platform mobility can lead to partial competition between platforms or to the expansion of the range of applications. In historical experience, mobility only rarely disrupts the market structure of established platforms.

III.4 Platform Mobility Edges Toward Competition: The Super Minicomputer

The development of the minicomputer and mainframe segments left a gap among small administrative sites, such as medium-sized firms or sub-divisions in larger firms. Mainframes were too expensive and minicomputers lacked software and support services. This gap was filled by the entry of technical minicomputer platforms into business computing.²² The invention of the business superminicomputer by entrant DEC was the breakthrough. In terms of hardware engineering, DEC's supermini platform, called the VAX series, was very similar to its technical-ancestor, the PDP series.²³ However, from a marketing standpoint, the supermini category was new.

The virtue of the superminicomputer over a mainframe was its combination of convenience, capacity, reliability, and low cost for small applications. A moderately sophisticated user could avoid centralized management and save on the servicing costs. This initially appealed to experienced users who were unsatisfied with the 360/370 platform, which presumed that users would be willing to pay for considerable service and customized support (Inmon (1985), Friedman and Cornford (1989), Cortada (1996)). It also appealed to geographically remote

²² This gap was widely recognized and might have been filled in other ways. Extending an existing mainframe line would have permitted compatibility and growth. Alternatively, a whole new platform, unconstrained by design history, could be optimally designed for a new customer body. The latter strategy was attempted, with limited success, by IBM, Wang, and others in the early 1970s. Their "small business systems" were much more expensive than a standard (dedicated application) minicomputer. They included servicing, training, and a maintenance arrangement.

²³ The hardware for a supermini such as the VAX-11/780 was not really much different from its technical ancestors (i.e., the PDP-11). The advances were well within normal platform growth: enlarged capacity (for multiple users), superior peripherals and air-cooled technology (Bell and Mudge (1978)). Though DEC also sold computers under the VAX name for technical uses, we focus on the commercial segment.

divisions in large organizations who did not want to contact a centrally managed mainframe through low-grade communication links.²⁴

Other technical minicomputer firms entered superminicomputing as well, but DEC was the most successful throughout the 1980s. After an initial period of innovation, superminicomputers began to be adopted for simple administrative tasks. These systems also began to compete at the margin for some mainframe sites.²⁵ Over time, the supermini segment took on features associated with increasing ESC and backward-compatibility equilibrium, with corresponding tendencies toward concentration and persistence. The VAX series remained dominant and backward compatible over several generations of hardware, while many third-party suppliers developed products for it and grew up around it.

Entry into business computing was cheaper than the creation of a new platform. It involved the mobility rather than the *de novo* creation of platform components (e.g., hardware). It was more competitive than a founding because there was less product differentiation between existing and entrant platforms. Superminicomputing impinged on the mainframe's traditional administrative customer body, but did not retain all the size and capabilities of the mainframe platform.

III.5 IBM's Reaction to Mobility as Illustration of the Incumbent's Problem

Superminicomputers threatened the rents of incumbent computing platforms, and so provided IBM a strong incentive to respond competitively. In sharp contrast to its very effective competition against other mainframe producers, IBM was ineffective here. This was a key step in the creation of a more segmented computing industry, with different platforms serving different users. IBM's difficulties illustrate three things. First, they illustrate the general issues facing an incumbent platform vendor after the entry of a successful mobile platform. Second, these events

²⁴ Basically, the smaller the system, the easier it is to use and maintain. Experienced users will only need a small intermittent technical and staff to support them.

²⁵ After an initial period of marketing VAX systems in the traditional technical manner, DEC added software tools and applications, simple servicing and maintenance contracts, and peripherals. DEC also began to add processors from a range of sizes and retained compatibility across the whole product line for much of the 1980s (Pearson (1992)). Wider general purpose use in business arrived with each addition of third-party application software (Friedman and Cornford (1989)). Multi-user capability suited the minicomputer to text-editing and printing, and other small data-based tasks such as multi-cash-register monitoring and report-writing or simple accounts receivables (Inmon (1985), Cortada (1996)). Software firms such as Oracle (databases) grew up to serve this segment. User-groups also grew up around these business applications and users began to design the VAX platform into commercial applications.

illustrate that the strategic actions of the established platforms, even those with strong ESC and standards persistence, cannot necessarily stop every attempt of entry from a mobile platform. Third, the outcome of competition between a mobile platform and an established platform is not deterministic; several outcomes are possible depending on the strategic choices of firms.

Entry left incumbent IBM facing a strategic choice: leave super minicomputing to DEC and others; compete in super minicomputing with a cheap System/370 compatible machine; or compete with an incompatible machine. IBM chose to design and introduce the 4300 product family, a much-criticized compromise because it attempted to compete with partial compatibility. Hardware and software products within the 4300 platform were compatible with each other. The new platform was partially backward compatible with the System/360/370. Ultimately, users thought of the IBM superminis as a separate product line, so IBM gained few of the benefits associated with compatibility (between the 360 and the 4300) for its partial-compatibility pains.

The wisdom of the incumbent's specific strategy choice is less important than the general problem the choice illuminates.²⁶ As already noted, incumbent platforms that are responsive to old customers may be ill-suited to new opportunities. In this case, mainframe customers, including smaller ones who might defect to a supermini platform, valued backward compatibility with the System/360/370. In contrast, new customers wanted cheap, versatile machines near the technical frontier. As it turned out, these goals could not be simultaneously satisfied. Retaining backward compatibility placed technical constraints on developing a product for potential supermini buyers.

III.6 Successful Platform Mobility: The Business Microcomputer

Another important example of platform mobility can be seen in the creation of the business microcomputer segment. The invention of the business microcomputer drew on an existing technical (hobbyist) base but created a new segment associated with applications like spreadsheets, word processing, and entertaining games. These were "personal" computers, meaning that the user would be a single white-collar worker. Overwhelmingly, the business microcomputer expanded the range of applications of computing and involved only very modest

²⁶ A number of explanations are consistent with events, such as: (1) IBM's managers did not foresee the new segment and responded after observing rivals' success; (2) IBM was better off being a "strong second"; (3) incentive problems within IBM (e.g., cannibalization, especially with the system/3) hindered the development of new platforms. Articulating an accurate organizational or strategic history of this decision does not influence the main point about the tension between technical progress for a new users and the limitations of satisfying old users.

competition with pre-existing platforms.²⁷

This parallel aside, the microcomputer platform moved into business computing much faster than the super minicomputer. Minicomputer platforms took decades of technical development before entry into business/administrative segments. In contrast, the hobbyist microcomputer arose in a few years in the late 1970s before moving into business use. Smaller platforms, disorganized and anarchic as they were, could add and change key features very rapidly. For example, individual firms, like Apple, could quickly attempt to make useful microcomputers.²⁸ Complementary assets associated with participating in the platform could move quickly and independently. In addition, microcomputing was an informal and open-standards-oriented industry at its outset. Perhaps surprisingly, anarchic rabbles appear to achieve coordinated change more rapidly than do coordinated efforts within the firm.

III.7 Indirect Entry Needs a Theory

The history of microcomputing and of minicomputing are parallel at each of two stages. These platforms first served technical segments that had not been previously served. After a period of accumulation of knowledge, mostly of an engineering sort, each developed software and marketing capabilities for business uses. This brought each platform closer to competition with existing platforms. We label this historical pattern “indirect entry” and suggest that it needs a theory.

The main competitive elements of this theory are as follows: All the participants in existing platforms, both buyers and sellers, approach new opportunities after long periods of investment in platform specific components. It is costly for a new platform to recreate the same investments found in old platforms. ESC and standards persistence make established platforms particularly difficult to dislodge. Thus, a new platform will have the highest likelihood of attracting enough customers to get over the “acceptance” hump if it serves a completely new, uncontested, segment of demand. Then, after some investment in components, a platform has

²⁷ The PC replaced time-sharing on large computers and dedicated purpose word processing on minis. Neither was an important use of those kinds of computers. Small businesses simply did not use the microcomputer the way a larger business might use a super minicomputer or an even larger one a mainframe.

²⁸ For example, Wozniak designed the Apple I in a matter of weeks and (with a little more help and more direction) the basic design for the Apple II in a matter of months. Bricklin designed the first spreadsheet, Visicalc, for the Apple II in a few months. In other words, once the design goals were known, a small team of talented engineers could quickly execute them. See Freiburger and Swaine (1984), ch 7.

sufficient capabilities to attract a larger network of suppliers and support, develop its own ESC around the standards embedded in the platform, and move toward more contested bodies of demand. It can eventually grow strong enough to move into another established platform's market.

In “capability mobility” theories of firm entry, existing firms move capabilities from one market to another.²⁹ The mobility of computer platforms shares the capability-mobility element. There are two important novelties to the mobility of platforms, however. The first is the distinction between a platform and a firm. Unsponsored platforms share some but not all of the behaviors of firms. The second, perhaps more important distinction is that indirect entry of platforms requires a general equilibrium analysis. Mobility of platforms depends on the particular markets which might be entered and the particular firms which might enter them. Mobility of platforms also depends on the relationship between clusters of markets, both technical and business. New business platforms tend to enter business computing after they build up capabilities serving technically-oriented customers. The stock of potential entrants into business computing also depended on the historical creation of new technical computing segments in the past.

III.8 Stability and Progress after Segment Foundation

With the exception of one competitive platform shift, the IBM PC, the 1980s were a period of stability in the structure of the industry. No important platforms were invented and no new segments opened up.³⁰ The period was one of rapid progress, but not of radical innovation or the founding of whole new markets. Technologists with anarchic tastes either mourned the passing of the earlier period or asserted that the PC or the minisupercomputer were radical innovations that were going to replace mainframes.

It is important to explain why the period of stable structures within segments persisted for most of the decade. There could not have been a stronger contrast between this period of stability, in which IBM and DEC reached extraordinary revenue levels, and the more recent times of the

²⁹ See Davidow (1986), Teece (1986) on theories of “niche creation,” and Caves and Porter (1977) for the theory of “capability mobility” at the firm level.

³⁰ Some technologists object to this characterization, pointing to such great technical achievements as portable PCs. However, portable computers from Osborne, Compaq, etc., used existing platforms and were compatible with desktop machines. Another great technical achievement, high-end parallel processing, has not yet diffused to mainstream business use, remaining within a small niche of highly technical users. The closest thing to a new segment foundation was the diskless workstation, but that involved more of a cheapening of already available (on minicomputer) capabilities, for all its later importance.

1990s, in which both firms have been battered by competitive events.³¹ Our explanation emphasizes that the segments remained largely separated in the 1980s. The respective dominant platforms from each segment avoided competition. The forces associated with ESC and standards persistence were localized within segment, encouraging distinct technical and market trends.

In mainframes and super minis, the general characteristics of the population of demanders remained largely fixed. However, in these large-system segments the computers became cheaper and more powerful. These same users continued to invent new programs to take advantage of cheaper price/performance. This invention, and the resulting demand for new components, helped finance more technical progress, which further reinforced the capabilities of each platform. Improvements in software and networking tools, such as relational database systems and communications controllers, let users propose and build more complex applications. A bank, for example, could network its automatic teller machines to central computers for real-time account balance verification. This kind of on-line transaction processing application extended the uses of the database, without fundamentally changing it.

The network of buyers and sellers for personal computers also took advantage of advancing technological opportunity, but in a very different way. The PC evolved into a faster, cheaper, and (especially) easier to use tool for individual workers. This segment grew as the PC diffused to many users, many of whom were new to computing. A small number of applications software packages -- word processors, spreadsheets, and a few others -- were used by a great many users. The distinct trends in large computers and small segments reflects technical progress localized to a platform.

Buyer/seller relationships and vertical industry structure also differed across segments. Large systems sellers continued to offer considerable service and support. Professional users in MIS departments and highly skilled sales forces continued an information-rich dialog between buyers and sellers. The platform-coordinating vendor, such as IBM and DEC, continued to offer many of the technical advances in large-system software and networking, maintaining the ESC-based advantages of established platforms. In contrast, by the end of the period microcomputer hardware and software were sold at arms length through retail outlets and decentralized

³¹ Some analysts time the competitive crash by earlier events, when several business minicomputer firms, Wang, Prime and Data General, began experiencing financial troubles in the mid 1980s (due primarily to competition from work-stations and personal computers). We think this is a red herring for an analysis of the dominant firms and platforms

distribution channels. Many technical advances in hardware and software came from firms other than the platform sponsors.³²

These differences in structure reflect the localization of positive feedback. The technical capabilities of different kinds of computers became more divergent in terms of features. Smaller computers were growing steadily more powerful. The larger computer segments needed their customers' applications to continue to grow in size and ambition, motivating them to demand large-sized systems. This demand, in turn, allowed incumbent vendors to differentiate their systems from smaller computers. Networking large systems provided an important part of this continuing growth. So too did the close bilateral relationships between IBM and mainframe customers, which led to the ongoing collective invention of more ambitious large systems applications.

IV. THE FORCES FOR STRUCTURAL CHANGE

We now turn to the conditions encouraging radical structural change. Our analysis locates those in the links between segment equilibrium and the wider equilibrium of the whole industry. Shifts in the dominant platform(s) serving a segment -- very disruptive competitive events -- are rare and require special circumstances. For such shifts to occur, the broader industry must contain many of the elements that would make up a new effectively competitive platform. A weakness in the incumbent platform, perhaps caused by the advance of technology or a strategic blunder by the lead vendor for the established platform, frequently helps successful entrants. We see these forces not only in the competitive crash of the early 1990s, but also in some important precursors: the replacement of CP/M by the IBM PC, and IBM's late entry into superminis. These are important examples of indirect entry growing more competitive.

Another kind of radical structural arises when buyers maintain platform continuity but control of the platform shifts among sellers. This follows from vertical competition for control of a platform among the sellers of its various components, and arises only in situations of divided technical leadership. We examine an important example, the shift in control of the PC platform from IBM to Microsoft and Intel.

³² For further descriptions of this era, see Inmon (1985), Friedman and Cornford (1991), Cortada (1996), and the relevant discussions in Steinmueller (1996), Bresnahan and Greenstein (1997), and Bresnahan and Saloner (1997).

IV.1 Successful Entry and Platform Competition: The IBM PC

By 1980 the PC had grown more versatile, fueled by the increasing size of the segment. The existing “8-bit” architectures had aged technically sooner than expected and needed to be replaced with a “16-bit” hardware architecture that would permit larger and more powerful programs. Prior to the development of strong ESC around the 16-bit architecture, the market structure could have developed several different ways. One possibility was the emergence of a backward-compatible extension of the existing CP/M platform. Alternatively, there might have emerged a new incompatible platform embodying either a proprietary architecture or a completely open and unsponsored one. As it turned out, all of these were tried.³³ In the resulting competitive struggle, one platform did come to a position of dominance, the IBM PC, which was not backward compatible. It had vertically disintegrated invention, an open design, and a sponsoring firm taking the lead. The vertical industry structure that resulted was chosen by IBM consciously, and IBM’s choice met wide acclaim.

IBM’s strategy combined two elements in an “open architecture.” IBM used other firms’ technology in key areas such as the microprocessor, the operating system, and many applications. For example, in hardware, IBM depended on Intel for chip designs and chip production. They relied on Microsoft for the operating system and on many firms for peripherals, software applications, and computer languages. The invention of key platform components was intentionally divided so IBM could have all its components ready upon introduction.³⁴ The architecture was open in a second, distinct sense. Any user could add hardware or software components to an IBM-compatible PC, and eventually any firm could make an IBM-compatible computer. This opened possibilities for expanding the capabilities of the systems using the platforms.

The strategy led to a quick introduction and spectacularly large hardware sales for many years. IBM’s marketing capability and reputation helped overcome the standards persistence built around the established 8-bit platforms.³⁵ The number of platforms available to buyers decreased

³³ For example, CP/M-86 was available on both IBM and non-IBM hardware. An Apple-supplied system might also have become the dominant platform.

³⁴ IBM’s PC division aimed to introduce their product in a year. This was only possible with outside suppliers. See, e.g., Chopsky and Leonsis (1988), Langlois and Robertson (1995), or Cringely (1994).

³⁵ This is the standard theory of IBM the “strong second” succeeding commercially where others innovated. See,

quickly, as one might expect when ESC shape market structure. Growth was rapid, as many third party firms added compatible capabilities for the IBM-sponsored platform.³⁶

This was the first competitive replacement of an established computing platform by another. The rarity of such events illustrates the coincidence of necessary circumstances. First, there was an entrant with a strong market and marketing position, from outside the segment but within the industry. Second, the entrant could introduce a new platform without undercutting its position in existing segments.³⁷ Third, the incumbent platforms were facing an abrupt and technically uncertain transition in their architecture, in this case from 8-bit to 16-bit computing. This transition weakened the standards persistence associated with the established 8-bit platforms, leaving open the possibility of meeting new technical opportunities in a variety of ways. Fourth, the entering platform quickly met the market need for rapid technical advance, which, in this case, was linked to the platforms' strategic choice for an open architecture and vertically disintegrated market structure.

Coincidences of circumstances like this do not arise frequently. The general rule is one of platform persistence and continuity for customers, while new platforms flow to new uses.

IV.2 The Mobility of Firm Capabilities, reprise: IBM AS/400 Enters Superminicomputing

IBM had, as we have noted, failed to establish dominant platforms in the technical minicomputer segment and in the business superminicomputer segment. By the late 1980s, IBM had several incompatible systems targeted at small businesses. Each platform had its fans, but none of these were dominant and none were compatible with the mainframe products.³⁸

The AS/400 superminicomputer from IBM was clearly a separate platform, not backward compatible with any previous IBM mainframe and only partially compatible with previous

e.g., Davidow (1986) or Teece (1986) for similar summaries.

³⁶ By the mid 1980s the hardware dollar sales in PC platforms equaled hardware dollar sales in mainframe platforms and exceeded it by the end of the decade

³⁷ This stands in sharp contrast with IBM's superminicomputer entry in the late 1970s. See Leonsis & Cheopsis (1988) on the well-known story of how IBM set up a separate company to pursue the PC, free of delays associated with inter-divisional politics.

³⁸ IBM had been in the midrange segment for some time. The System/3 family and the 9370, not to mention the 4300 family, each generated enough revenue to please a small firm. None of them dominated a business segment or defined an enduring multi-generation platform, however. In that sense, they were not successful.

midrange IBM product offerings.³⁹ However, it was a technical breakthrough in its communication capabilities, and it included a wide variety of new applications, available at introduction. IBM's Rochester team applied some of the past lessons of platform development to this market. It developed the AS/400, using outside suppliers for many components and software, value-added resellers as distributors, and a distribution structure designed to elicit rapid feedback from customers. The platform quickly developed the positive feedback associated with ESC. In more recent times, this system has allowed IBM to become the largest business minicomputer vendor.⁴⁰

In the past it was not clear whether super minicomputers were just small mainframes and thus had to fall within the span of mainframe compatibility. By the late 1980s, however, the separateness (and non-IBMness) of the business supermini segment were well established. The success of the VAX platform helped define the super minicomputer platform as a separate segment, limiting the benefits to IBM from extending compatibility from the mainframe segment. Freed from the strategic mismatch between its existing business and the new one, IBM introduced a new platform with a vertically disintegrated structure. Then it was able to use its marketing capabilities.

As with the previous example of a successful new platform, the entrant was from within the industry, with a strong market presence, and used many marketing and technical assets already in place. The entry did not undercut any successful platform from established firms. It also met a need for rapid technical advance, developing a structure for positive feedback around the platform.

IV.3 Divided Technical Leadership Yields Internal Entrants: From IBM PC to Wintel

At the outset IBM had a strong role as the coordinator of the decentralized technical progress in the vertically disintegrated PC platform. Later, this role slipped away to IBM's early partners, Intel and Microsoft.⁴¹ This shift was competitively disruptive and deserves close analysis.

³⁹ The closest previous systems were the System 36 and 38.

⁴⁰ See Bauer, Collar, and Tang (1992) for an insider's view of the project management and product launch. See Andrews, Martin, Elms, and Simeone (1989) or West (1992) for analyses of technical capabilities and design goals.

⁴¹ See Ferguson and Morris (1993) for a detailed recounting of these events. IBM coordinated improvements in color monitors with the VGA standard after a challenge from a non-IBM sponsored alternative. IBM owned 13% of Intel for a period and helped coordinate the introduction of the Intel 80286 processor. IBM coordinated

In the early 1980s, IBM had the advantage of being the leading seller of microcomputer hardware. This dominant position, backed by a strong brand name, let IBM move the platform forward by using a combination of market forces and negotiation with collaborators. IBM emphasized incremental technical progress with backward compatibility. Other firms' hardware and software products needed to work with IBM equipment.

From IBM's perspective vertical competition first broke out in a combined vertical-horizontal form. An important microprocessor, the Intel 80386, was first used by Compaq in a working computer system. The Intel-Compaq combination undercut IBM's claim that it steered the design of the platform. The new generation of PC was defined by the chip inside, not by the IBM design surrounding the chip. Intel and Compaq achieved this coup using the same advantage IBM had used to start the PC category: speed. Other PC firms began to make 80386-based systems, billing them as "industry standard," not "IBM-compatible." The platform's sponsorship structure became similar to CP/M.⁴²

IBM did not stand by passively. Its managers had several strategic options and chose a particular strategy that failed. They attempted to regain control of the standard for the PC by connecting it to IBM proprietary technology. Their strategy employed three weakly connected innovations that together formed a new-generation PC. These innovations were the MCA hardware bus architecture, the OS/2 operating system, and the token ring local area network protocol.

The failure of the strategy became most apparent after the introduction of new hardware using the proprietary bus architecture, MCA, which came without a new (bug free) operating system, OS/2. Though the PS/2 improved performance, it was not backward compatible without effort, nor was the hardware by itself a large improvement in a non-networked environment. A committee of other PC hardware sellers proposed a less dramatic performance leap and backward compatibility with the "Extended Industry Standard Architecture." Customers and makers of

improvements in the DOS operating systems even though these were supplied by contractual collaborator Microsoft.

⁴² With hindsight, these latter events were foreshadowed by the internal disorganization associated with the introduction of the PC embodying the 286 chip, as well as very early clone challenges to IBM's hardware. See, e.g., Cringely (1992) or Carroll (1994). However, the loss of control was not recognized earlier than the 386 chip generation. Contemporary observers did not attribute it to any single managerial decision within IBM associated with 286 machines.

“plug in” cards overwhelmingly chose the latter. What had been “the IBM PC” became “the industry standard “PC,” with models named for the Intel microprocessor inside.

It was in this position of dramatically weakened control that IBM split with Microsoft over operating systems. OS/2 began as a joint venture between those two firms, and then split into two competing products, OS/2 from IBM and Windows from Microsoft. IBM found itself in an operating systems standards battle without control of the hardware architecture and with a promised, but much delayed, operating systems project. Shortly after the IBM PC was eclipsed by the industry standard PC, the industry standard PC was eclipsed by the Wintel standard. The platform had a new leadership structure from which IBM was excluded.

It is possible to second-guess, as many analysts have, IBM’s strategic wisdom (or lack of it) in choosing a proprietary and backward-incompatible innovation⁴³. For our purposes, it is more important to emphasize the general lessons about vertical competition. When different firms possess roughly equivalent technical skills and supply complementary components, technical leadership is easily divided among them. It is quite difficult to maintain leadership over a platform under such conditions. It is easy to take strategic actions in component markets that look like mistakes in retrospect, eclipsed as they are by faster introductions from equally capable component rivals. Thus, when platform leadership shifts vertically, it threatens proprietary platform rents, even if -- from the user’s vantage -- the platform changes little. The outcome for such vertical competition is not deterministic; it depends on the strategies of the particular firms and the conditions determining competition between them. That said, when technical leadership is potentially divided among many firms, it is possible for control to shift quickly, even within the span of one generation of new products.

IV.4 The Competitive Crash of the Nineties

The early 1990s saw competitive entry by new platforms into the mainframe and superminicomputer segments. The new “client/server” platform was a departure. It was a platform of platforms, networked together.⁴⁴ The destruction of rents at IBM and DEC marked a major change in market structure and industry equilibrium outcomes.

⁴³ Ferguson and Morris, like many other analysts, look only at the PC market and argue strongly that IBM strategically blundered. In the next section, we offer an explanation of these events in light of wider IBM product strategy and a broader view of the industry’s evolution.

⁴⁴ The phrase “client/server” has both a specific technical meaning and a broader connotation. We use it in the latter sense, referring to any networked platform with highly intelligent terminals.

Our explanation of this dramatic change uses all the analytical elements from the last sections. There was a strong entrant platform from outside the segment but from within the industry, and its entry was congruent with the existing product strategies of many firms. The incumbent platforms had important technical weaknesses associated with long histories of continuous backward compatibility and the new needs of users, and these weaknesses were difficult to remedy. Finally, the new platforms were associated with divided technical leadership and a vertically disintegrated structure, devaluing the traditional management strengths of the incumbents.

In most common client/server arrangements, standard minicomputers or workstations act as “servers” running database management systems or related software. Standard PCs are “clients” presenting information to users, possibly for further analysis. To be sure, some new software has to be written to divide large, complex applications into client and server portions, which was not always easy. Nonetheless, the basic idea was easy to state: develop large, complex applications which are as powerful as a mainframe program and as easy to use as a PC program. Client/server applications were responsive to the greatest weakness of the established large-scale platforms, the difficulty of use.

Turning a PC into a client is not a costly way to enter a market. It keeps the marketing connection between the buyer and the PC intact. At many establishments, a PC already ran programs like spreadsheets, which could benefit from access to company wide or department wide data. Continuing to use Wintel PCs as clients preserved backward compatible human capital. It also made large complex systems much easier to learn and use.

Servers resembled earlier indirect entrants. They had developed technical capabilities over the years in response to the needs of technical users. In some uses, workstations and minicomputers had developed hardware (if not yet the software) to perform many of the traditional functions of mainframes or superminicomputers (e.g., communication with external bodies, file management and load allocation, etc.). The packaging of client and server, networked together, offered additional functionality. It also represented an incremental investment to the user and to a vendor trying to invent client/server solutions, allaying many concerns about backward compatibility.

This brought in firms with strong positions in pre-existing segments as participants in client/server. Leadership initially went to Microsoft, the dominant provider of operating systems

for the client, and Oracle, the most popular provider of server database software.⁴⁵ A stunning variety of startup firms entered as well. A few standard arrangements of platforms have emerged by the mid 1990s. Yet, as of this writing, insufficient time has passed for ESC to determine a persistent market structure for this platform in all relevant segments. There is also considerable competition for vertical control of the platforms that are emerging.⁴⁶

IV.5. IBM's Anticipation of Client/Server

Mainframes were hard to use, particularly in comparison to a PC. IBM, the largest incumbent, was the firm most competitively harmed by the potential entry of an easy-to-use large-scale platform. IBM's managers recognized this threat and tried to repair their own proprietary platform in anticipation (and later in response) to this threat⁴⁷ The attempt failed because of the changing conditions of competition, not because of IBM's failure of technical or market foresight.

IBM anticipated client/server with a company-wide product strategy, potentially offering unified solutions for company-wide networked computing. It drew on the strengths of both PCs and larger systems. In particular, IBM's Systems Network Architecture, SNA, was designed for seamless connectivity and networking between computers of all sizes. Systems Application Architecture, SAA, was to be an applications-development architecture that spanned mainframes to PCs. Had these initiatives met broad market success, large applications would have received the benefits of client/server on a proprietary platform built of networked IBM mainframes and IBM PCs.

We have already analyzed the failure of this strategy. The pieces of SAA and SNA that failed were the proprietary IBM PC technical initiatives of the late 1980s: the MCA bus, OS/2,

⁴⁵ For example, leadership did not go to the leading vendor of PC network software in the late 80s, Novell.

⁴⁶ So it is that many industry analysts remark on the different "sub-platforms" within the dominant platform. Some of these divisions clearly represent fights for control over the whole platform, but some also do not. That said, the open issue is whether this variety presages more than one dominant client/server platform in a future equilibrium, where those platforms perhaps differ by application or primary customer base. These may also represent an equilibrium hierarchy in market structure, where control over a dominant platform is divided on the basis of standards in some software applications or other configurations that build on top of the predominant platform.

⁴⁷ A folk explanation of this competitive failure is "IBM was late to recognize client/server." This is false. One can see past the hagiographic tone of Killen (1988) that IBM executives articulated the goals of client/server early. Recognizing the market trends were not the issue. The core issue was that it was virtually impossible to execute a strategy in a market structure where equilibrium forces were leading away from centralized control of the platform.

and the token ring LAN. The strategy failed in the PC market, not in the nascent client/server market.

Like the entrant client/server platform, IBM's networked computing strategy re-used components from existing segments. The strategy was therefore dependent on success in each segment. When IBM lost control of the PC platform, its proprietary client/server strategy was also destined to fail. The overall IBM networked-computer platform never competed head to head against (what are now labeled) client/server platforms, for IBM's strategy died too soon. This failure is symptomatic of a larger shift in the forces determining market structure. Platforms that can vertically disintegrate can do so quickly if many firms have technical strengths suitable to different components.

IV.6 What Changed in the 1990s?

The SNA and SAA strategy is the familiar IBM coordinating strategy. The strategy had succeeded for more than 25 years in the large systems segments, an extraordinary length of time in computing. IBM has been unable to regain control of technical change in large scale client/server, and no other platform steerer has emerged⁴⁸. Focusing on IBM's apparent previous failures, however, misses the more general and important observations for the future of computing structure. All sellers attempting to control parts of the client/server standard are compelled by market forces to have at least partially open strategies. This is a radical shift in industry structure for large systems segments. It is not a temporary artifact of the decline of one previously dominant firm. It is an irreversible change in market structure. What caused this change?

First, client/server architectures necessarily have divided technical leadership because they re-use components. A platform steering strategy would have to coordinate all of the components of client/server architectures. To do this, a firm would have to make progress on each component at or near the technical level of the leader in that component. A firm would need to advance operating systems technology not much slower than Microsoft, databases not much slower than Oracle, servers not much slower than Sun, and microprocessors not much slower than Intel, while coordinating all those technologies toward a common goal. This would be an extraordinarily task, and it is no surprise (with the benefit of hindsight) that even IBM's attempt at it failed.

As of this writing, several platforms compete for buyer acceptance. The theory of ESC and standards persistence from Section II strongly argues that the equilibrium market for

⁴⁸ As of this writing, Microsoft is perhaps the most likely firm among many to someday take up this role.

platforms within a given segment will be concentrated and will persist for a long time. The theory of industry equilibrium from Section III suggests that those segments will reflect different classes of needs for applications. The analysis of this section also suggests that technological competition in the client/server market will likely be characterized by divided technical leadership and vertical competition for rents. Our framework cannot predict the specific winning firms nor the technical details of the eventually dominant platform. The equilibrium outcome will depend on particular firm strategies, and (as yet unknown) technical constraints on platform capabilities and user needs.

IV.7 Popular Theory: Superior Form for Organizations Revealed by Competition

Our theory of platform competition explains both why the industry has become more competitive and why the dominant established firms could not take any effective competitive initiatives to prevent erosion of their rents. It sharply contrasts with theories of incumbent firms as “dinosaurs” or incompetently managed behemoths, which have been especially popular among technologists. The vertically integrated technology firm -- IBM or DEC--is thought to be a slow inventor, while the specialized “silicon valley” style firm is focused and therefore superior at technology. The competitive story is a simple one in which the new superior form triumphs over the old inferior one.

While there are attractive elements to this organizational story, it is strikingly incomplete. The specialized computer component firm was not a brilliant organizational invention waiting to be discovered in the 1980s. Instead, the entire market equilibrium of the computer industry shifted, which devalued management and organizational skills associated with coordinating component innovation. IBM and DEC had used that skill to incorporate the specialists’ invention into platforms they controlled. It was the change in vertical competitive conditions, combined with the indirect entry of a new platform, that devalued the coordinators’ role.

One reason industry observers were so surprised by the competitive crash of the 1990s is that they over-used theories tailored to firm strategy in particular market segments. These theories proved to be inappropriate when the conditions underlying the industry’s overall structure shifted. IBM acted as the aggressive entrant in several of the events that anticipated the competitive crash. Thus it seemed that the firm was in fine shape. Yet those near misses meant that disruptive entry and structural change were growing easier, to the eventual disadvantage of IBM.

V. CONCLUSION: CHANGE AND CONTINUITY IN MARKET STRUCTURE

We conclude by integrating our analysis of the forces leading to concentration and persistence within industry segments and our analysis of entry into a unified explanation of what has changed and what has stayed the same in computer industry technological competition. Constantly expanding technological opportunity has been one, but only one, determinant of how the computer industry is organized. Market forces played a large role in determining what kinds of computers served which kinds of uses, supplied by what kinds of firms, and organized into what kind of industry.

V.1 Change and Continuity

The phenomena which any analysis of computer industry structure must explain are a heady mixture of rapid change and long term stasis.

- ! There has been a dramatic growth in the use of computers. At the intensive margin this has been supported by increases in quality and decreases in price for existing computer types. At the extensive margin, new types of computers have been invented.
- ! Dominant platforms have persisted in the main industry segments for decades. The organization of supply in different segments persisted in a stable form for much of the decade of the 1980s.
- ! The 1990s have seen dramatic changes in industry structure, especially in the most successful firms and most lucrative parts of the industry. The industry has become vertically disintegrated, inhabited primarily by specialized firms. Technical leadership is divided. Hardware and component markets are more competitive. Sellers complain rather than brag about the pace of change.
- ! There are also some striking elements of continuity in industry structure. First, only a few platforms serve most uses. Second, most uses are still served by platforms updated through generations of backward-compatible improvement.

Our explanation for these tendencies is a mixture of powerful forces for stasis and for change, with long, slow growth in the forces for change crossing a threshold in the early 1990s.

V.2 Ongoing Technological Opportunity and the Forces for Stasis

Technological opportunities have constantly expanded. Most of the time, this opportunity has been realized by (1) steadily improving the computer hardware and software in computer platforms offered to already-recognized groups of demanders and (2) occasionally inventing new

platforms, or re-inventing them, so as to serve an entirely new body of demand. This tendency for technological competition at two distinct margins to leave market relationships unchanged needs an explanation.

V.2.a Continuity within Segment

A similar phenomenon arises in all platforms, technical and business. In all cases, hardware grows better and cheaper, software grows more capable and easier to use, and networking permits applications to have a wider geographic span.. Technical advances in hardware, software, and networking make obsolete the purely technical basis for earlier computers; sellers adapt new processes and invent new products regularly. Yet, rapid technical change within the segment respects backward compatibility. Buyers' relationships to platforms are very long-lived, as are marketing relationships between buyers' and sellers. .

This persistence within segment followed from the same economic forces that explain segment-level concentration. Buyers' and sellers' investment in platform specific knowledge and software lead both to the importance of ESC and of standards persistence at the platform level. The importance of mutual investment between buyers and sellers was the key to the invention of the platform. Concentration and persistence follow from the most basic economics of the industry. Segments with business buyers, where these forces are strong, tend to have few platforms. Platform shifts within already-served segments are correspondingly rare. The dramatic platform shift in personal computing, such as when the IBM PC replaced CP/M, occur infrequently.

Importantly, our explanation does not require a single platform sponsor. In recent times, we have seen concentration and persistence with multiple sellers and/or with divided technical leadership. These changes do not matter for our story because ESC theory and the platform persistence theory are robust. The implications we use do not depend on the specific industrial organization of supply or on the ownership structure of the asset leading to platform persistence.

Following the logic of this argument, we believe that the basic forces of ESC and platform persistence still underlie the industry's structure. More specifically, this leads us to a prediction. The 1990s have seen a period of competitive new platform formation in networked computing. We predict concentration and persistence of platforms will re-emerge. We are confident in this prediction because (1) the demand forces behind it are as strong as ever and (2) we need to assume very little about strategic supply under our robust theory.

V.2.b Change: Opening Up New Markets by Non-disruptive Platform Entry

The opening up of new segments could, in principle, take a variety of different forms. It nonetheless has two empirical regularities. First, completely new platforms flee competition, serving new kinds of needs. Second, the same engineering capabilities first serve technical customer bodies and only then, with suitable reformulation of software and marketing capabilities, business ones. The analysis of these regularities illuminates (1) powerful forces for stasis in computer industry structure and (2) a slowly-growing loophole, a nascent force for change.

Steadily expanding technological opportunity underlies changes to this industry. Engineers imagine making new kinds of computer hardware, software, and networks. Yet, a platform is a complex web of engineering and market-oriented components. A new platform does not have an installed base of users nor an experienced group of software developers. Supply by a new, technically oriented seller may also not have a marketing department in place.

Young platforms have systematically succeeded in segments where the marketing components were least important or could be assembled most readily. A new platform tends to have commercial success if it initially avoids competing with an existing platform. There will be a period of time spent building up the complementary market and marketing assets. If the platform is really new, that early period will also be the time in which the most demanding technical problems are being solved, some by trial and error. As a result, new platforms serve new uses.

Mobility toward business segments occurs only after technical expertise accumulates among the platforms' hardware and software vendors (sometimes in the same firm). Even then, the movement tends to avoid competition with pre-existing platforms, instead broadening the range of business users. First competition-fleeing and then competition-avoiding entry have created supply to a wide range of diverse uses.

V.3 Disruptive Platform Entry and Shifting Vertical Control

The exceptions to these empirical regularities do not contradict the theory. We view them as confirmations. However, they call for a careful look at the broader dynamic of the industry.

V.3.a More Disruptive Platform Entry over Time.

There are two important recent cases in which the creation of a new platform has led to competition with a pre-existing platform -- the IBM PC and client/server. The incidents are alike in one sense. In both instances, the new platform already had significant market or marketing assets. These formed the basis for a successful new entry of a platform, offering the new platform

advantages in the early period. As a result, competition with the existing platform was possible.

It is unwise to read these incidents as meaning that there is a trend away from platform concentration and persistence within segments. The forces for that are still in place. Instead, they reveal a changing relationship between market structure equilibrium in individual segments as the overall computer industry grew. These disruptive changes came from outside the individual segment, and they came after competitive capabilities grew up outside the individual segment. Indirect entry has grown over time as a force because of changes in the overall industry. Disruptive entry still needs to overcome considerable boundaries in any particular segment.

V.3.b Vertical Competition and Standards Stealing

Our explanation also examines changing control of the standards in what used to be called the IBM PC. Here, there was no disruption of the platform's relationship to its customers. Instead, the control of the platform moved vertically among suppliers. The platform had been controlled by the computer hardware manufacturer and original designer, IBM. Later, control moved to the manufacturers of microprocessors (Intel) and of operating systems (Microsoft) with the latter firm perhaps dominant. Here again we see an important change in strategic interactions among firms despite continuity in market outcomes at the platform level.

Once again, this is a story of platform continuity within segments. Change arose in the wider industry (more potential entrants with greater capabilities), leading to divided technical leadership in the segment. Divided technical leadership offers the opportunity for shifts in control of the standard from one leader to another or to others. As a client/server platform (or some other networked computing platform) becomes important, it will be interesting to see how these strategies change over time. We offer no prediction on this score, for things have changed and many firms now think in terms of taking control of standards. Competition to control standards is a new feature of many industry segments. Divided technical leadership and the struggle for control of standards among firms selling products that work together are the sources of this competition. It is the mix of competing and cooperating at once that marks this as a new kind of competition and quite likely marks the current industry structure as transitory and unstable.

V.4 Long Run Changes Were Hard to Forecast and Perhaps Permanent

We have left unanswered the speculative (but popular) question of whether established firms could have done anything to avoid recent changes. For this issue, we examine the long-run dynamics in this industry. There are two relevant trends. First, there is increasing vertical

disintegration. Second, there is a broadening of technical and market capabilities at many kinds of firms in many segments. Both of these happened for reasons only loosely connected with their eventual influence on competitive outcomes. Both occurred for reasons that now appear inevitable. Yet this is 20-20 hindsight and the reasons were obscure at the time incumbents might have acted.

Very powerful forces let a variety of different firms and platforms dominate in a variety of different computing segments. Foundings involved (initially) weak entrants avoiding competition. The extension of existing (somewhat stronger) platforms to the new uses in the new segments also avoided competition with existing platforms. Yet, incumbents too were constrained by backward compatibility. As users grew too diverse, a single platform failed to meet all their needs. IBM was successful in microcomputer and minicomputer segments only when it entered with platforms that were distinct from its mainframe offerings. More precisely, it is hard to imagine that an incumbent could have succeeded any better in a wider variety of segments than did IBM.

Vertical disintegration within the microcomputer platform was partially chosen by IBM. A prescient firm could have tried to prevent it from arising in PCs. Any such attempt would have failed. Platforms with divided technical leadership are distinct from sponsored ones. They differ along three mutually reinforcing dimensions. One is speed of innovation. The second is the (competitively important) vertical disintegration of technical effort. This structure developed in the PC and workstation segment and was starting to arise in third-party software markets in other segments. It could not have been delayed for long by even the most brilliant incumbent. The third appears to be firm structure: a new form of firm decision making appears to be better undertaken by fleet, specialized firms.

IBM chose speed with the new structure when it was an entrant into microcomputing. It did so because this was the only way to establish a new platform against existing platforms, which were advancing rapidly. The computing industry today has a vertically disintegrated, speed-based competitive structure. The move to a new industry equilibrium devalued platform steering capabilities, the strengths of IBM and DEC. This is the source of private loss of economic value.

V.5 Implications for Competition Theory

We have taken a market equilibrium perspective in order to explain the changing balance between

structural stability and disruption from the mid 1960s to the present. We argue that the same forces have been in place throughout the history of the computer industry. To see their changing balance over time and across segments calls for a careful positive analysis with a wide scope. Our analysis necessarily skims many books of detail, using secondary sources for corroborative evidence. Historical work has often used non-economic and non-equilibrium analysis to understand change, sometimes burying analysis in the detail. Theoretical work has developed pieces of the explanation, but neither synthesized explanations nor resolved contradictions. We work at the boundary between the analytical and the historical, filling the gap between them.

Much of our analysis of the forces for stability in industry structure drew on well established competition and industry structure theory. To make it fit the computer industry, we changed a focus on the firm to a focus on the platform. With this change, we can understand both why each segment in business computing tends to have long lived platforms, and why some elements of industry equilibrium are the same now as they were thirty years ago. Our analysis of the forces for change took us into areas where competition theory is not yet strong. Here we have identified two gaps. The first is in the theory of indirect entry. Our observations here point to links between market structure in the individual segment and the broader industry equilibrium. They also point to links between organizational theory and competition theory. Indirect entry takes time because the entity that competes, be it a firm or a platform, needs to mature. The second gap in theory relates to divided technical leadership and vertical competition. Our observations here point to a new kind of analysis of competitive entry threats to established positions, coming from sellers of complements rather than of substitutes. They also point to a new kind of link between the way supply is organized vertically and the degree of competition for rents. We should not be surprised that an industry as inventive and important as computing throws up new challenges to the analysis of industry structure and of competition.

REFERENCES

- Andrews, D., J. Martin, T. Elms, D. Simeone, *The AS/400 Revolution: Guide to the AS/400 and IBM Strategy*, Connecticut: ADM Inc, 1989.
- Baldwin, C. A., and K. B. Clark (1997), "Sun Wars," in *Competing in the Age of Digital Convergence*, (Ed) D. B. Yoffie, Boston, MA: Harvard Business School Press.
- Bauer, R. A., E. Collar, and V. Tang, *The Silverlake Project: Transformation at IBM*, New York: Oxford Press, 1992.
- Bell, C. Gordon, and J. Craig Mudge (1978), "The Evolution of the PDP-11," *Computer Engineering: A DEC View of Hardware Systems Design*, Digital Equipment Corporation.
- Besen, S. M. and G. Saloner (1989), "Compatibility Standards and the Market for Telecommunications Services," in *Changing the Rules: Technological Change, International Competition and Regulation in Telecommunications*, R. W. Crandall and K. Flamm (Eds.), Washington, DC: The Brookings Institution.
- Besen, S., and Farrell, J. (1994), "Choosing How to Compete: Strategies and Tactics in Standardization," *Journal of Economic Perspectives*, Volume 8 number 2, Spring.
- Bresnahan, T. and S. M. Greenstein (1997), "Technical Progress and Co-Invention in Computing and in the Use of Computers." *Brookings Papers on Economics Activity: Microeconomics*, Pp. 1-78.
- Bresnahan, T. and F. Malerba (1997), Industrial Dynamics and the Evolution of Firms' and Nations' Competitive Capabilities in the World Computer Industry, mimeo, Stanford Computer Industry Project.
- Bresnahan, T. and G. Saloner (1997), "Large Firms' Demand for Computer Products and Services: Competing Market Models, Inertia, and Enabling Strategic Change," in *Competing in the Age of Digital Convergence*, (Ed) D. B. Yoffie, Boston, MA: Harvard Business School Press.
- Brock, G. W. (1975a), "Competition, Standards, and Self-Regulation in the Computer Industry," in *Regulating the Product: Quality and Variety*, Richard Caves and Marc Roberts (Eds.), Cambridge, MA: Ballinger Publishing.
- Brock, G. W. (1975b), *U.S. Computer Industry: A Study in Market Power*, Cambridge, Mass: Ballinger Publishing.
- Carroll, P., *Big Blues: The Unmaking of IBM*, New York: Crown Trade, 1994.
- Caves, R., and M. Porter (1977), "Entry Barriers to Mobility Barriers: Conjectural Decisions and Contrived Deterrence to New Competition," *Quarterly Journal of Economics*, May 1977, Vol. 91(2), pp. 241-261.

- Chandler, Jr., A. D. (1997) "The Computer Industry," in *Competing in the Age of Digital Convergence*, (Ed) D. B. Yoffie, Boston, MA: Harvard Business School Press.
- Chopsky, J. and T. Leonsis (1988), *Blue Magic: The People, Power and Politics Behind the IBM Personal Computer*, New York: Facts on File Publications.
- Cortada, J. W. (1996), *Information Technology as Business History: Issues in the History and Management of Computers*, Westport, CN: Greenwood Press.
- Cringely, R. X., (1992), *Accidental Empires*, New York: Harper Collins.
- David, P. A. (1985), "Clio and the Economics of QWERTY," *American Economic Review*, Papers and Proceedings, Vol. 75, p. 332 - 337.
- David, P. A. and S. Greenstein (1990), "The Economics of Compatibility Standards: An Introduction to Recent Research," *Economics of Innovation and New Technology*, 1(1/2).
- David, P. A. and W. E. Steinmueller (1994), "The Economics of Compatibility Standards and Competition in Telecommunications Networks," *Information Economics & Policy*, December 1994, Vol. 6, No. 34, pp. 271-291.
- Davidow, W. H. (1986), *Marketing High Technology: An Insider's View*, New York: Free Press; London: Collier Macmillan.
- DeLamarter, R. T., *Big Blue: IBM's Use and Abuse of Power*, New York: Dodd, Mead, 1986.
- Dorfman, N. (1987), *Innovation and Market Structure: Lessons from the Computer and Semiconductor Industries*, Cambridge, Mass.: Ballinger.
- Farrell, J., H. Monroe and G. Saloner (1994), "Systems Competition versus Component Competition: Order Statistics, Interface Standards, and Open Systems," Stanford University, mimeo, July 1994.
- Federal Trade Commission (1996), "Anticipating the 21st Century: Competition Policy in the New High-Tech, Global Marketplace," <http://www.ftc.gov/opp/global.htm>.
- Ferguson, C. H. and C. R. Morris (1993), *Computer Wars: How the West Can Win in a Post-IBM War*, 1st ed., New York: Times Books: Random House.
- Fisher, F. M., J. J. McGowan and J. E. Greenwood (1983), *Folded, Spindled, and Mutilated: Economic Analysis and U.S. vs. IBM*, Cambridge, Mass.: MIT Press.
- Fisher, F. M., J. W. McKie and R. B. Mancke (1993), *IBM and the U.S. Data Processing Industry: An Economic History*, New York: Praeger Publishers.
- Fishman, K. (1981), *The Computer Establishment*, 1st ed., New York: Harper & Row.

- Flamm, K. (1987), *Targeting the Computer: Government Support and International Competition*, Washington, D.C.: The Brookings Institution.
- Flamm, K. (1988), *Creating the Computer: Government, Industry, and High Technology*, Washington, D.C.: The Brookings Institution.
- Freiberger, P. and M. Swaine (1984), *Fire in the Valley: The Making of the Personal Computer*, Berkeley: Osborne\McGraw Hill.
- Friedman, A. and D. S. Cornford (1989), *Computer Systems Development: History, Organization and Implementation*, New York: John Wiley and Sons.
- Gort, M., and S. Klepper (1982), "Time Paths in the Diffusion of Product Innovations" *Economic Journal*, September.
- Greenstein, S. M. (1997), "Lock-in and the Costs of Switching Mainframe Computer Vendors: What Do Buyers See?" *Industrial and Corporate Change*.
- Inmon, W. H. (1985), *Technomics: The Economics of Technology & the Computer Industry*, Dow Jones-Irwin.
- Katz, B. and A. Phillips (1982), "The Computer Industry," in *Government and Technical Progress: A Cross-Industry Analysis*, Richard R. Nelson (Ed.), Pergamon Press, pp. 162-232.
- Killen, M. (1988), *IBM—The Making of the Common View*, Boston: Harcourt Brace Jovanovich.
- Langlois, R. N., and P. L. Robertson (1995), *Firms, Markets and Economic Change, A Dynamic Theory of Business Institutions*, New York: Routledge.
- Liebowitz, S.J. and S. E. Margolis (1995), "Path Dependence, Lock-In and History," *Journal of Law, Economics and Organizations*, April.
- Nelson, R., and S. Winter (1977), *An Evolutionary Theory of Economic Change*, Cambridge, Mass.: Belknap Press of Harvard University Press, 1982.
- Packard, D. (1995), *The HP Way: How Bill Hewlett and I Built our Company*, New York: Harper Collins Publishers.
- Pearson, J. P. (1992), *Digital at Work: Snapshots from the First Thirty Five Years*, Burlington, MA: Digital Press.
- Phister, M. (1979), *Data Processing Technology and Economics*, Digital Press, Santa Monica.
- Pugh, E. W., L. R. Johnson and J. H. Palmer (1991), *IBM's 360 and Early 370 Systems*, The MIT Press.
- Reback, G., S. Creighton, D. Killam, N. Nathanson (1994), *Microsoft White Paper*, Wilson,

Sonsini, Goodrich & Rosati, Palo Alto, CA., November 14, 1994.

Sobel, R. (1986), *IBM vs Japan: The Struggle for the Future*, New York: Stein and Day.

Sobel, R. (1981), *IBM: Colossus in Transition*, New York: Bantam.

Steffens, J., (1994). *Newgames: Strategic Competition in the PC Revolution*, New York: Pergamon Press.

Steinmueller, W. E. (1996), "The US Software Industry: An Analysis and Interpretive History," in *The International Computer Software Industry: A Comparative Study of Industry Evolution and Structure*, (Ed) David Mowery, New York: Oxford.

Sutton, J. (1991), *Sunk Costs and Market Structure*, London, England: The MIT Press.

Teece, D. J. (1986), "Profiting from technological innovation: Implications for integration, collaboration and public policy," *Research Policy*, 15, p.285-305, North-Holland.

Utterback, J., (1994), *Mastering the Dynamics of Industrial Change*, Cambridge: Harvard Press.

Watson Jr., T. J., and P. Petre (1990), *Father Son and Co: My Life at IBM and Beyond*, New York: Bantam.

West, K., *Inside IBM: Technologies and Strategies for the 1990s*, Charleston, SC: Computer Technology Research Corporation, 1992.