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Source: *The Journal of Industrial Economics*, Mar., 1999, Vol. 47, No. 1 (Mar., 1999), pp. 1-40

Published by: Wiley

Stable URL: https://www.jstor.org/stable/117505

THE JOURNAL OF INDUSTRIAL ECONOMICS 0022-1821
Volume XLVII March 1999 No. 1

TECHNOLOGICAL COMPETITION AND THE STRUCTURE OF THE COMPUTER INDUSTRY*

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We examine thirty years of computer industry market structure. Our analysis explains the persistence of dominant computer firms, their recent decline, and the changing success of competitive entry. It emphasizes the importance of technological competition between computer 'platforms', not firms. This aspect of competition has changed little over time. Two things did change. Young platforms serving newly founded segments eventually challenged established platforms across segment boundaries through a process of indirect entry. Vertically disintegrated platforms have led to divided technical leadership in important segments. The result is an industry with far more technological competition.

I. INTRODUCTION

THE STRUCTURE of the computer industry changed dramatically in the 1990s after several decades of stability. From the earliest days of the Computer Age, the same dominant firm, IBM, sold mainframe computing to the same class of customer. Despite the concentrated industry structure, technical progress opened many commercial opportunities. Rather than compete directly with the established leader, entrants—of which there were many—opened up new market *segments*, such as minicomputers or microcomputers. Each of these segments, in turn, was characterized by concentrated supply and the persistence of leading suppliers. After years of gradual evolution, computing in the early 1990s saw a 'competitive crash,' in which seller rents were drastically reallocated across market

*We thank the Alfred P. Sloan Foundation, the Center for Economic Policy Research at Stanford University, the Charles Babbage Institute, and the Arnold O. Beckman Research Foundation of the University of Illinois for support, and Andrea Scott, Victoria Danilchouk, Tom Hubbard, Harumi Ito, Mike Mazzeo, Judy O'Neill, and Pablo Spiller for helpful conversations. We received helpful comments at the June 1992 conference on Industrial Organization in Vienna, and at the University of Oregon, University of Illinois, University of California, Berkeley, Stanford University and Northwestern University. Comments from Severin Borenstein, Charles Clarke and two referees were very helpful.

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segments. Firms that had previously supplied different segments now competed for the same customers. This change in industry structure resulted in much more aggressive behavior and a more competitive market generally.

The goal of this paper is to explain, within the same analytical framework, the causes behind the period of stable industry structure and the 'competitive crash' of the early 1990s. We examine the computer industry at the segment- and industry-wide levels. For the segments the relevant issues concern the sources of industry concentration and the persistence in market structure. For industry-wide equilibrium, we ask a more difficult question about changes over time in entry: What factors led entrants to flee competition against established firms in one era, but to challenge them later? To reach our analytical goal we simultaneously characterize the overall industry equilibrium and strategic behavior within each segment. By embarking on so sweeping a project, we will hold ourselves to an evidentiary standard that is broad rather than deep. We seek to provide an explanation, not detailed analysis, of the principal structural features of the computer industry.

The first important feature of the computer industry is rapid and sustained technical innovation. Integrated circuits and many other electronic components continually become better, faster, and cheaper, providing opportunities to improve existing computers as well as to design new kinds of hardware. While the development of new technical opportunities must play a role in any analysis of the computer industry's history, the development of technological opportunities cannot provide, by itself, much of an explanation of changing industry structure. It is only one factor behind changes in firm behavior, changes in buyer choices of vendors, and changes in the locus of rents.

The second important industry feature is the nature of commercialization of innovation. Supply in the newer segments (like microcomputers) is organized in a new way, with much more vertical disintegration and specialization than in the older mainframe segment. In the transformation of the industry, smaller entrepreneurial firms have come to replace larger established ones. Yet, this feature also cannot, by itself, provide an explanation; it is as much a result of changes in industry structure as it is a cause. Moreover, this transition did not resemble the direct replacement of an ineffective older organizational form with a newer and better one. Entry became an effective force only quite slowly. Why? First, demanders in different segments value different aspects of technology and supply. Of particular importance is the distinction between customers in commercial offices and more technically sophisticated customers in factories and laboratories. These differences slow entry. Second, these same differences permit new segments to 'incubate' technologies and business models that would have failed had they entered directly against IBM early on. The new, more specialized, vertically disintegrated form of supply, and its associated technologies, is more effective in some competitive regimes than others. We introduce the concept of *indirect entry*, analyzed in more detail below. Indirect entry links within-segment equilibrium and industry-wide equilibrium by identifying the sources of potential entrants and by analyzing the factors that make specialized entrants effective in some situations but not others.

A third industry feature pertaining to demand also bears directly on the 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 obeys 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 share interchangeable components, so many sellers and 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: accordingly, there tend to be few platforms in any segment. Long-lived investments also lead to platform persistence, whether for cost-minimizing, coordination-failure, or strategic reasons.

We argue for a view in which both demand forces and supply forces lowered entry barriers for *firms*, not necessarily *platforms*. 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 the case of 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 was controlled at first by a single firm, but later decentralization led 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. Some of the same forces that caused the persistence of a small number of distinct, long-lived platforms in commercial computing in the 1960s are still in place. What has changed is the nature of competition for the control of platforms in the 1990s. To make sense of this change in control, we introduce a new market structure concept, *divided technical leadership*, a structure in which a number of firms possess the capability to supply key platform components. Today, the same firms that compete to control technical standards also make products that work together (or 'interoperate' in industry lingo). We argue that divided technical leadership is inevitable in today's computer industry and that divided technical leadership makes firm entry easier.

Our analysis links several distinct arguments from a wide range of history and segments; accordingly, we develop it in stages. In Section II we discuss the role of the platform; the analysis draws on familiar theory and confines itself within market segments. In Section III we examine industry-wide equilibrium: specifically, the competitor-fleeing behavior of the pre-'crash' founders of new segments and post-'crash' entrants' mobility from one segment to another. In Section IV we examine the likelihood of successful cross-segment entry. In Section V we describe industry-wide conditions favoring entry that have improved over time. We close by combining these elements to explain the conduct and time pattern of technological competition in this most important modern industry.

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. We define the platform as a bundle of standard components around which buyers and sellers coordinate efforts. We link a platform to robust implications for a segmented market structure. Having built our within-segment framework, we conclude this section by examining a segment market structure with quite different demand and supply characteristics from those in IBM mainframes.

II(i). *The Invention of the Platform: The IBM System/360*

From the mid-1960s onward, IBM dominated the mainframe segment with a single computing platform that began life as the IBM System/360.[1] It is by now a cliché that IBM was the most successful computer firm in the 1960s by virtue of its technical and marketing prowess. We examine this commonplace remark in order to draw 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

[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.

computers of different processor speeds and disk sizes. IBM established plug compatibility for System/360 hardware: monitors, tape drives, disk drives, controllers, card-readers, and central processing units (CPUs). Application software and databases on one system could be easily moved to another within the platform. IBM developed technical standards for product interoperability and embedded these standards in new versions of all its mainframe products. The nexus of compatibility standards between hardware and software is the hallmark of a *platform*; the System/360 was a platform sponsored by IBM. A customer-written program adhering to the platform standard would function on any machine drawn from a wide variety of system configurations.

A great deal of uncertainty surrounded the business use of computers in the 1960s. Platform compatibility was valuable to business customers because the sunk costs of adopting a platform—most notably, customer- and platform-specific software and training, and complex changes to business systems—could be spread over a much larger base of commercial activity (both because the investments would be longer-lived and because they could be stretched to meet new customer computing needs). The purchaser of a System/360 acquired the option to increase capacity without scrapping these sunk investments. Three factors proved pivotal to IBM's initial success: the technical advance inherent in the System/360, marketing through a field sales and service force to assure customers that their investment would be protected and enhanced, and the value of the option to increase capacity within the same platform.

Total investments by IBM and its customers in System/360 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 competitor 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 became the dominant platform.

II(ii). *A Robust Theory of Dominant Platforms: Endogenous Sunk Costs*

Powerful forces limit the number of platforms in market equilibrium. A platform is a device for coordinating disparate rapidly improving

[2] For a fuller discussion on this and some other historical topics, see the Appendix at the JIE editorial web site at http://haas.berkeley.edu/~jindec/.

[3] See Topic 3, in the Appendix.

technologies and for market coordination between buyers and sellers. Platforms have significant scale and scope economies, which bear important strategic implications. In this section, we introduce a *robust, positive* theory of concentration in terms of platforms. Our emphasis on the positive theory of why there are few platforms stands in contrast to a large normative literature debating whether platform concentration is socially beneficial.[4] We emphasize robustness because we will later reuse the platform concentration theory in a wide variety of computer industry contexts over several decades.

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, which are independent of 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 exhibit 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 and users to improve the products for users (Sutton's [1991] empirical analysis explored expenditures such as advertising and other brand-enhancing expenditures in food and beverage industries.). An expenditure is classified as an ESC if it exhibits the following properties (which can also be viewed as assumptions in the Sutton model):

1. *Irreversibility*. The expenditure must be sunk (irreversible).
2. *Specificity*. Expenditures raise buyers' valuation of a specific product or set of interrelated products, not necessarily the whole industry demand curve (except in the rare case when that set of products is the only set available).
3. *Unlimited efficacy*. The efficacy of additional expenditure cannot be exhausted. At any level of expenditure, it must be possible to spend still more to attract customers.
4. *(Near-)Unanimity about efficacy*. A large fraction of potential customers must respond to the expenditure.

Sutton compellingly argues that an unconcentrated industry structure is impossible in the presence of ESC. If industry structure were fragmented, a firm could invest in ESC, thereby drawing many customers to itself. Accordingly, firms that do not invest in ESC can expect to garner only small market shares. Thus, when ESC are important, markets will only

[4] Much of this emphasis arises out of the *US vs IBM* antitrust case. Further details in the Appendix.

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

sustain at most a few firms in equilibrium. The synthesis does not need to specify the precise links between competitive outcomes, the source of expenditures, and the strategies of sellers, e.g., whether the first mover will have an advantage. A very important result is that, when ESC are important, demand growth does not lead to fragmentation; a larger market will have higher ESC, not more firms, in equilibrium.

We apply Sutton's theory to platforms in the computer industry (instead of firms). As we will see in a moment, the assumptions of the theory about demand (embodied in the properties of ESC) are satisfied for business computing as long as we are talking about platforms, not firms' product lines. The distinction matters in the case of platforms supplied by more than one firm.

We have already seen that Properties (1) and (3) applied to mainframe computing. Sellers' development and coordinating costs are clearly sunk. Buyers also sink costs into building their parts of a platform, through in-house software development and training. Much of the cost of building buyer/seller 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 extensive 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 apply Property (2) to the computing industry, we clearly must change its scope of application from the 'firm' to the 'platform.' Expenditures to improve a platform raise the demand for components of the platform, regardless of seller. It happened that IBM sold almost all of the components of the System/360 platform. Yet if RCA had succeeded in its strategy of cloning System/360, its and IBM's investments would have raised the demand for the entire platform, not just for each firm's own products. Similarly, if a third party vendor or a user group were to have developed a peripheral that only works on the System/360, it would have raised the demand for the entire platform.

Property (4), which concerns customer (near-)unanimity, limits the scope of the theory. Our argument that 1960s business computer users valued the same kinds of ESC depended on the details of their technical and economic circumstances. Other classes of users (e.g., academic researchers, factory-floor technicians, retailers) would not necessarily value compatibility with System/360 highly, and might be served by other platforms with other market structures. Ultimately the theory predicts that there will be a concentrated structure, measured in terms of platforms, within the computer industry segment.

The possibility of multifirm supply within a specific platform does not vitiate the theoretical prediction that there will be few platforms. If the firms were to invest in the same compatible platform, individual firms' ESC would tend to reinforce one another by expanding demand. This would lead a segment to support few platforms even if there were many supplying firms. Of course, if each firm pursues its own (mutually incompatible) platform strategy, we are back in the world described directly by the Sutton theory. In either case, equilibrium will be concentrated in platforms. While unimportant in the case of 1960s mainframes, this observation about multifirm supply will become quite important in the later history of the industry.

We discern two general lessons about computer industry structure. First, an ESC industry arose in computing after the invention of the platform, specifically the IBM System/360. Strong ESC forces for concentration in platforms (not necessarily in firms) were unleashed. The second general lesson is closely related but frequently overlooked: Platform creation is not merely a feat of engineering; it is part of an implicit contract that shapes market relationships between buyers and sellers of computers. In turn, these market relationships shape market structure.

II(iii). *Platform Persistence and the IBM System/370*

The 1970s saw continued high concentration in the mainframe segment, still dominated by IBM.[6] Many System/360 users migrated to using the much more capable System/370. (In the jargon of the industry, the System/370 was *backward-compatible* with the System/360.) IBM needed to undertake substantial new technical investments to design the backward-compatible upgrade. As a result, users were not forced 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?

Technical advance in the late 1960s and early 1970s opened opportunities for designing new components in computing. Newer mainframe platforms offered desirable features, such as timesharing, that the System/360 lacked. IBM faced a dilemma: Since the System/360 had not been designed with these features in mind, and it would be prohibitively expensive to add them, how could IBM introduce a new product family without alienating the mass of consumers (the 'installed base') who had already purchased System/360?

IBM's solution was to manage a coordinated move forward. The timesharing System/370 offered backward compatibility with the System/

[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].

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 ease of transition was especially 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 experienced the System/360, so that backward compatibility was widely valued.

The move forward involved two difficulties. First, IBM needed to make expensive design changes to incorporate technical innovations (such as time sharing) into a backward-compatible system. IBM invested heavily in the new technology, both hardware and software, abandoning most of the specific technical advances that underlay the earlier System/360. Second, outside firms made many hardware and software components which were compatible with the evolving platform. Many producers of 'plug-compatible' data storage devices, for example, had grown by selling to buyers of System/360s. 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 structure and industry equilibrium. IBM's customer relations continued on the same basis as before the introduction of the System/370. IBM did not alter its 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 of these trends, competitors continued their exit from the mainframe systems business.[8]

We do not wish to dwell too long on the history of the mainframe market segment. We note, however, that IBM managed several similar coordinated migrations through the 1970s and 1980s. Two hard realities steadily eroded IBM's long-term position. First, technical opportunities

[7] See Greenstein [1997] for analysis of these costs at the technical and organizational level.

[8] Most notably, General Electric and RCA invested heavily and exited after substantial losses (See Fisher *et al.* [1983]). Outside the US, government-sponsored firms also failed, with only a few exceptions (see Bresnahan and Malerba [1997]).

arose outside the IBM mainframe platform's traditional ambit, yet still needed to be incorporated in a backward-compatible way. User groups, trained system engineers and operators, programmers, and sales and service personnel, inside and outside IBM, held a stake in these decisions, constraining more tightly the set of feasible future migrations. Second, the vertical disintegration of the platform's production continued. Many peripherals, much software and service, and, at various times, even the computer hardware could be obtained from suppliers other than IBM.

Although IBM's competitive tactics evolved over time, IBM retained firm control over the platform. By setting technical standards, IBM determined what could be connected to an IBM-compatible mainframe. IBM's long-term customer relationships, its competitive response to all direct threats, and its ownership of key platform elements, such as the operating systems, maintained this position of control. The inventive efforts of other platform participants—customers, user groups, and third-party providers of compatible components—improved the platform. This collective action rebounded to all participants' benefit, most notably to IBM's.

II(iv). *The Economics of Persistence*

A large body of economic theory has emerged recently to explain the persistence of *de facto* standards, which stand at the heart of computer platforms. A central idea of this theory is positive feedback among the different components constituting a platform.[9] In this section, we consider the applicability of this theory to the computer industry.

This theory of standards makes a variety of assumptions about buyer *and* seller behavior, insofar as it is as much about markets as about technical change. These assumptions are consistent with, but more detailed than, those of the ESC theory:

1. *Platform specificity*. Buyers and sellers of technology make platform-specific investments. Different sellers may offer different components within the platform. An interface standard governs compatibility among components within the platform.
2. *Investment durability*. At least some of the platform-specific investments are long-lived; these investments influence the costs and benefits of future technical improvements by sellers and market choices available to buyers.

Mutually reinforcing behavior arises when standards coordinate behavior

[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.

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 tend to sustain platforms for long periods. For example, according to this theory IBM did not have to introduce the advances of the System/370 technology before 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 origin and demise of a platform. 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 products, such as software or other components. *Positive feedback*, or increasing returns to adoption, 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, but this event may not necessarily come easily or quickly.

Related literature debates the normative implications of a third assumption, which possesses a strong 'coordination failure' aspect:

3. *Uncertainty*. Coordination among agents relevant to the standards adoption decision is costly.

Stated broadly, assumption (3) is plausible in markets in which new technology may not meet with wide adoption. Theories vary in the exact manner in which different agents have difficulty coordinating which decisions, with concomitantly varying normative conclusions about persistence. The seller's role in these models of persistence is typically interpreted as either being the efficient coordination or the exploitative preservation of a monopoly position. Our goal of a positive analysis leads us to use assumptions (1) and (2) only; we avoid any variant of (3) and eschew its normative implications.[10] Under (1) and (2) we predict that the pattern of platform persistence seen in the System/360 to System/370 migration is typical, but make no comment on its desirability.

II(v). *When a Platform Is Neither Dominant Nor Persistent: Minicomputing*

Not all computer segments share the same demand characteristics. As demanders' valuation of platform compatibility falls, the forces underlying ESC and persistence weaken. We illustrate this point by introducing the minicomputer segment and contrasting it with the mainframe segment. In

[10] For discussion of the competing theories of the welfare economics of lock in, see Topic 10 in the Appendix.

the 1960s and 1970s the minicomputer market structure was consistently less concentrated than that of mainframes. While Digital Equipment Corporation (DEC) enjoyed the largest market share, its lead over competitors such as Data General, Prime, and Hewlett-Packard was not nearly as large as IBM's over its mainframe rivals.

When the new segment opened up in the late 1950s and early 1960s, the typical minicomputer customer was more technically sophisticated than the typical mainframe customer. In many of these applications, the user—an engineer or scientist—did not require a compatible family of systems since the processor was dedicated to repeated performance of the same computational task (e.g., communications or instrument control, large-system pre-processing, real-time data acquisition, or extremely precise calculation). In addition, technically sophisticated users did not require frequent servicing from the vendor to help them operate a system.[11]

As a result, the nature of commercial relationships between buyers and sellers differed from the mainframe segment. Minicomputer manufacturers did not have large field sales forces and support personnel in their customers' facilities. Sometimes the customer did not even know who made his 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, since sellers avoided costly distribution activities.

Technical users placed a lower value than business users on compatibility and seller-supplied service and support, preferring instead to perform it in-house. This had two important implications. First, minicomputers and mainframes evolved into recognizably different segments due to the heterogeneous demand for ancillary features (compatibility, service) of the computing product.[12] Substantial differences in customer tastes between the mainframe and minicomputer segments meant, importantly, that the minicomputer firms were sheltered from the most obvious and direct form of competition from IBM. Second, the mini-

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

[12] Segment boundaries can be difficult to define in an industry where the product is a general-purpose device. The demand differences here meant it would have been very difficult for IBM to extend the reach of the System/360-370 platforms to dominate the minicomputer segment as well as mainframes, because the specialized application software and service markets were too different to absorb extension of the same products and too small and low-value to support the creation of a parallel high-service structure.

computer segment was less concentrated and experienced less persistence of market share leadership than the mainframe segment.

II(vi). *When Dominant Platforms Persist Without Dominant Firms: Microcomputing*

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

In the late 1970s and early 1980s, the microcomputing platform with the 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 produced CP/M hardware. Software for this platform was (mostly) able to run on the hardware 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 remaining platforms with single sponsors, such as the Tandy TRS and the Commodore Pet, were not important competitors. Interestingly, both of the leading platforms relied on arms-length market institutions, such as retail stores or mail-order houses, to maintain contact with buyers, rather than forming bilateral relationships with customers through a field sales force.

The lack of a sponsor for the leading platform (CP/M) 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, there was an anarchic rabble of firms where each firm advanced one or more components.[14] Their efforts, only loosely coordinated by market forces, led to a market with only a few platforms, but many firms, in equilibrium.[15] The robust logic of the ESC theory requires only that a fragmented industry structure give rise to attempts to concentrate (which may not succeed). Success is more likely if these attempts are reinforced by positive feedback.

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

[13] The history is well known. See, e.g., Freiberger 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. See Topic 14 in the Appendix.

[15] See Farrell, Monroe and Saloner [1998] for analysis of the strengths and weaknesses of loosely coordinated component suppliers against a vertically integrated organization.

multifirm supply is the same as *uncoordinated* supply. Indeed, it is clear that the unorganized CP/M community did not behave as a single platform sponsor would have; it made more mistakes of coordination. By not pausing to coordinate with other suppliers, the community may also have moved forward more rapidly through piecemeal technical progress in components. Speed (of technical progress) is the benefit and coordination failure the cost of unsponsored platforms, or of multifirm supply more generally.

The early dominant microcomputing platforms did not persist as long as platforms in the mainframe segment. Both CP/M and the Apple II, based on '8-bit' microprocessors, were eclipsed by a major technological innovation: the advent of '16-bit' microprocessors. We return to the resulting dislocation and to the limits to platform persistence in our next section.

The 16-bit era also saw many new platform offerings, but (once again) only two platforms dominated: the platform that began as the IBM PC, and the Apple Macintosh. Each has demonstrated persistence, surviving well over a decade, through a stunning amount of technical progress. The Macintosh is a sponsored platform with a *closed* hardware architecture, meaning that Apple maintains exclusive control over its interfaces. The PC is more complicated. It began as the *IBM* PC; IBM sponsored the technology and chose a vertically disintegrated structure for the invention and production of components. Later, the platform became simply an 'industry standard architecture,' an unsponsored structure. Still later, after its original operating system was succeeded by the backward-compatible Microsoft-sponsored Windows on Intel-sponsored microprocessor designs, 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, once established, existing platforms tend to persist. These outcomes occur because buyers and sellers jointly value compatibility, even when supply is not concentrated and the persistence of *firms* is in doubt. The complex and changing sponsorship structure of the PC supports the robustness of the positive theory of platform concentration and persistence. Rapid and coordinated technical progress has kept the IBM PC platform in a dominant position through many generations of products over the past fifteen years.

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 considering the period, 1960–1989, in which expanding technical opportunity 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. Although the creation of these new platforms represented technically impressive innovation, in general these events did not disrupt the market structure of established platforms in established market segments.

The competitor-fleeing behavior of entrants is, of course, related to concentration and persistence within segments. To these we add another element: *time-to-build* for platforms. Complexity and complementarity of platform components imply potentially long 'gestation' before platforms obtain mature designs, before users realize the full benefit of a new platform and before vendors reduce the cost of producing for it. As a result, a newly invented platform will be a weak substitute for established platforms. This weakness leads entrepreneurs producing new platforms to flee competition to pursue 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(i). *A New Platform Flees Competition: Minicomputing*

We examined the structure of the minicomputer segment in Section II(v). Let us now consider this segment's founding. Entrants who supplied technical users avoided competition with existing mainframe platforms, for two main reasons. First, established platforms were difficult to dislodge due to the strong ESC and backward-compatibility forces in business computing. Second, creating a new platform for technically sophisticated customers (implicitly avoiding the business-oriented market) offered a greater prospect of success because costly non-engineering activities—service and support, marketing and distribution—were less critical to adoption.

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 by creating a separate segment. By serving technical users and catering to their particular needs, and by avoiding field sales and support costs, minicomputer vendors deliberately avoided (even the appearance of) competition with, and operated more cheaply than, IBM.[16]

[16] See Pearson [1992], particularly Chapters 4–6, for a recounting of these strategies.

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. Industry equilibrium selected those firms, like DEC, that used cost- and competition-avoiding strategies.[17] By the early 1970s, however, competition-fleeing was much more deliberate. For example, when Hewlett-Packard entered the minicomputer business, its executives were cognizant of the costs of competing for customers who wanted business applications. H-P, the instrument company, already had good relationships with technical customers. They also anticipated and avoided formidable competition from established mainframe providers.[18]

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

III(ii). *Competition-Fleeing and Segment-Founding: 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 physically small CPUs and independent individual computing, microcomputers and workstations, were based on an important technical advance, the microprocessor. Both segments' foundings were competition-fleeing.

Early microcomputer platforms created in the mid-1970s avoided competition by a new mechanism. The new segment initially was defined by the size and speed of the CPU, as well as the type of buyer, typically an individual 'hobbyist' who could assemble and program his own computer. Competition with minicomputer platforms was avoided because microcomputers were far smaller and cheaper than minis. Costs of complex distribution and support structures were also avoided. Diffusion and sales of these platforms depended on the sharing of technical information within a hobbyist community. The period saw very rapid technical progress but not concerted marketing efforts.[19]

[17] Equilibrium selection from a variety of firm types 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].

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

[19] See Freiberger and Swaine [1984] for the history from an engineer's perspective.

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.[20] These machines were developed and sold by entrepreneurial firms, with service and support similar to that for minicomputers. They were suitable for technical users, particularly engineers with numerically intensive problems. They avoided competition by being marketed as complements to, not substitutes for, minicomputers themselves. 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, enabling the new platform to evade direct confrontation with established platforms that could take advantage of ESC and standards persistence. Each new platform incorporated technological opportunities embodied in the newest hardware. A vibrant, technically sophisticated community that adopted the platform then supported rapid technical progress within the new platform. The platform avoided prohibitive marketing costs by selling directly to technical users and avoiding competition with existing platforms.

III(iii). *Platform Mobility*

We now turn to a distinct kind of segment-founding event, the movement of existing platforms towards new uses. In this section we describe two of these movements: the creation of the business minicomputer and the office microcomputer. These product repositionings constituted entry into business computing, in which incumbent platforms like the System/370 had previously served most users. An element of competition fleeing remained. Entrants ended up serving quite different subsegments 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. Many of the existing components of the platform can be reused, redesigned or retrofitted for new applications. Second, despite lower costs, an entrant's platform must still confront the forces that led to the persistence of the established platform in the first place (ESC and standards persistence). This confrontation can be resolved in a variety of ways; no single solution proved effective. Platform mobility can lead to partial competition between platforms, since their segments now overlap,

[20] For a wide variety of interpretations see, for example, Steinmueller [1996], Chandler [1997], and Baldwin and Clark [1997].

or to the expansion into new, non-overlapping, segments. In historical experience, mobility only rarely disrupted the market structure of established segments.

III(iv). *Platform Mobility Edges Toward Competition: The Superminicomputer*

The development of the minicomputer and mainframe segments created a gap in computer product offerings that ignored small administrative users, such as medium-sized firms or small divisions within larger firms. Mainframes were too expensive and minicomputers lacked the necessary software and support services. This gap was filled by the entry of minicomputer platforms into business computing.[21] The creation of the business superminicomputer by DEC proved a commercially viable breakthrough. In terms of hardware engineering, DEC's VAX supermini platform was similar to its ancestor, the PDP series.[22] However, from a marketing standpoint, the supermini category was new.

The main advantages of the superminicomputer over a mainframe were convenience, capacity, reliability, and low cost for small applications. The moderately sophisticated users to which these platforms were sold desired to avoid the costly centralized management and service[23] requirements of the System 360/370 platform (Inmon [1985], Friedman and Cornford [1989], Cortada [1996]). The supermini also appealed to geographically remote divisions in large organizations that did not want to contact a centrally-managed mainframe through low-grade communication links.

Other minicomputer firms entered superminicomputing as well, but DEC remained 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.[24] 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 complementary products for it.

Entry into business computing by an existing platform was cheaper than the creation of a new platform, in particular because the cost of developing

[21] This gap was widely recognized and might have been filled in other ways. Cf. Appendix Topic 21.

[22] Cf. Topic 22, Appendix.

[23] It is generally the case that 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.

[24] Cf. Topic 24, Appendix.

hardware components had already been incurred. This episode of mobility-entry, however, represented a greater competitive threat to mainframe computing than previous segment foundings because the differentiation between existing and entrant platforms was narrower than before.

III(v). *Incumbent Responses to Mobility-Entry*

Superminicomputers threatened the rents of incumbent computing platforms, which provoked IBM to respond. However, in sharp contrast to its very effective competition against other mainframe producers, IBM was unsuccessful in its efforts to dominate the supermini segment. This failure was pivotal in leaving the segmentation of the computer industry in place, with different platforms serving different users. IBM's difficulties in fending off superminicomputing rivals illustrate two propositions: First, established platforms, even those protected by strong ESC and standards persistence, cannot always forestall successful entry (in this case, by a mobile platform). Second, the outcome of competition between a mobile platform and an established platform is not a foregone conclusion; the choice and execution of strategy determines which one of several possible outcomes arises.

Entry posed the incumbent IBM with several choices: leave superminicomputing to DEC and others; compete in superminicomputing with a cheap System/370-compatible machine; or compete with an incompatible machine. IBM chose to design and introduce the (only partially compatible) 4300 product family, a much-criticized compromise. Hardware and software products within the 4300 platform were compatible with each other, but only 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 360/370 and the 4300).

The wisdom of the incumbent's specific strategy choice is less important than the general problem the choice illuminates.[25] As we have 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 the supermini platform, valued backward compatibility with the System/360/370. In contrast, new customers wanted cheap, versatile machines nearer the technical frontier. As it turned out, these goals could not be simultaneously satisfied. In this episode, backward compatibility constrained product offerings for potential supermini buyers too much.

[25] A number of explanations consistent with events are listed in Appendix Topic 25.

III(vi). *Successful Platform Mobility: The Business Microcomputer*

A second 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 customer (hobbyist) base but created a new segment associated with applications like spreadsheets and word processing. These were 'personal' computers, meaning that the user would be a single office worker (sometimes called a 'knowledge worker'). The business microcomputer greatly expanded the range of applications of computing, with only very modest competition with existing platforms.[26]

This parallel aside, the microcomputer platform moved into business computing much faster than the superminicomputer. Minicomputer platforms underwent decades of technical development before entry into the business and administrative segments. In contrast, the hobbyist's microcomputer of the late 1970s soon became the businessperson's PC of the 1980s. The disorganized and anarchic development of the smaller microcomputing platforms permitted a rapid addition and modification of key features. For example, individual firms like Apple could quickly attempt to make useful microcomputers.[27] Complementary assets associated with platform development could be created and improved quickly and independently. At its outset, microcomputing development was informal. The standards governing interfaces were *open*, which meant that they were not owned by any single firm. Perhaps surprisingly, anarchic rabbles appear to achieve coordinated change more rapidly than do coordinated efforts within the firm.

III(vii). *The Theory of Indirect Entry*

The history of microcomputing and of minicomputing paralleled each other at two distinct stages. First, these platforms served previously unserved technical segments. After a period of knowledge accumulation, mostly of hardware engineering expertise, firms supporting each platform developed the software and marketing capabilities needed to enter business uses. This pattern brought each platform closer to competition with existing platforms. We label this historical pattern *indirect entry;* its recurring importance suggests that it needs a theory.

The main competitive elements of this theory are: Buyers and sellers of existing platforms encounter new opportunities after having invested heavily in current-generation platform-specific components (hardware, software, training, etc.). To simply replicate the same investments in the

[26] Cf. Topic 26, Appendix.
[27] Examples and citations in Appendix Topic 27.

new platform found in old platforms would be prohibitively costly. ESC and standards persistence make established platforms particularly difficult to dislodge. Thus, a new platform increases its likelihood of attracting enough customers (a 'critical mass') if it serves a completely new, uncontested, segment of demand. Then, after some investment in components, a platform attains sufficient capabilities to attract a larger network of suppliers and support, to develop its own ESC around the standards embedded in the platform, and edge closer to contested bodies of demand. The new platform can eventually grow strong enough to move into an old platform's market.

'Capability mobility' theories of *firm* entry posit that existing firms shift capabilities to enter one market from another.[28] The mobility of computer *platforms* inherits the capability-mobility logic, but introduces two important twists. First, we emphasize the distinction between a platform and a firm. An unsponsored platform produced by more than one firm may, for example, exhibit faster technical progress than a platform identified with a single firm.

Second, and perhaps more important, indirect entry in computing calls for general equilibrium analysis. Repositioned technical platforms tend to enter business computing after having built a following among technically-oriented customers in new segments. The stock of potential entrants into business computing late in the industry was endogenous to the equilibrium of the whole industry. It was spawned in the then-nascent technical computing segment of an earlier era. More generally, indirect entry into a high-rent, high-persistence segment will occur where there is a suitably close technically, and suitably distant competitively, incubator segment.

III(viii). *Stability and Progress After Segment Foundation*

With the exception of the platform shift caused by the IBM PC, the 1980s were a period of stability in the structure of the computer industry. No important platforms were invented and no new segments opened up.[29] The period witnessed rapid progress, but not radical innovation or the founding of whole new markets. Technologists either mourned the passing of the earlier, anarchic, period or asserted that the PC or the mini-supercomputer were radical innovations that would replace mainframes.

We think it 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 the

[28] See Davidow [1986] and Teece [1986] on theories of 'niche creation', and Caves and Porter [1977] for the theory of 'capability mobility' at the firm level.

[29] For discussion of technologists' objections to this characterization, see Appendix Topic 29.

dominant platform sponsors—IBM and DEC—reached extraordinary revenue levels, only to be battered by the 'competitive crash' of the 1990s.[30]

Our explanation emphasizes that the 1980s' segments remained largely separated. The respective dominant platforms from each segment avoided competition with each other. The forces of ESC and standards persistence remained localized within each segment. In mainframes and superminis, the general characteristics of the population of demanders remained largely fixed over this period. However, within these large-system segments the hardware became cheaper and more powerful. These same users continued to develop new software to take advantage of the improved hardware. This invention, and the resulting demand for new components, helped finance further technical progress, which further reinforced the capabilities of each platform. Improvements in software and complementary tools, such as relational database systems and communications controllers, allowed users to 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 extended the uses of a bank's customer database, without increasing the cost of maintaining it.

The network of buyers and sellers for personal computers also exploited technological advances, but in a very different way: new applications were found for the new platform. 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, of whom the vast majority had never adopted any platform before. A small number of general-purpose software applications—word processors, spreadsheets, and a few others—were adopted by a great many microcomputer users, in contrast to the wide array of special-purpose software packages deployed on superminicomputers. The distinct trends in the two segments reflect the localization of technical progress to each platform.

Buyer/seller relationships and vertical industry structure also differed across segments. Large systems sellers continued to offer considerable service and support. Professional buyers in management information systems (MIS) departments and highly skilled sales forces continued their information-rich dialogue. The platform-coordinating vendor, such as IBM and DEC, continued to offer many 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 arm's length through retail outlets and decentralized distribution channels. Many technical

[30] For alternative views on the timing, see Appendix Topic 30.

advances in hardware and software were produced by firms other than the platform sponsors.[31]

These differences in vertical structure reflected the localization of positive feedback. The technical capabilities of different kinds of computers diverged. Smaller computers grew steadily more powerful, especially because of advances in processing speed, which opened up greater versatility and reliability. In the larger-computer segments, existing customers' applications to continue to grow in size and speed. This gave incumbent vendors an opportunity to use raw power to differentiate their systems from smaller computers, which couldn't 'scale up.' Networking large systems contributed an important part of this continuing growth. IBM, in particular, promoted close bilateral relationships with its mainframe customers, which led to the 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 embeds these conditions in the links between segment equilibrium and industry-wide equilibrium. Shifts in the dominant platform(s) serving a segment—very disruptive competitive events—are rare. For such shifts to occur, the broader industry must collect, from more than one segment, many of the elements that constitute a new viably 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, may help successful entrants. We discern 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 stimulating inter-platform competition.

Another kind of radical structural change arises when buyers maintain platform continuity but control of the platform shifts among sellers. This change 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 of divided technical leadership: the shift in control of the PC platform from IBM to Microsoft and Intel.

[31] For further descriptions of this era, see Inmon [1985], Friedman and Cornford [1991], Cortada [1996], and the discussions in relevant parts of Steinmueller [1996], Bresnahan and Greenstein [1997], and Bresnahan and Saloner [1997].

IV(i). *Successful Entry and Platform Competition: The IBM PC*

By 1980 the PC microcomputer had grown more versatile, fueled by the increasing size of the segment. The existing '8-bit' microprocessor architectures were on the verge of being superseded by a '16-bit' 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 (8-bit) CP/M platform. Alternatively, there might have emerged a new incompatible platform embodying either a proprietary ('closed') architecture or a completely unsponsored ('open') one. As it turned out, all of these were tried.[32] In the resulting competitive struggle, one platform did come to a position of dominance, the IBM PC, which was not backward-compatible with any of its predecessors. 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 (licensed from Intel after comparing several options), the operating system (licensed from Microsoft after a rebuff from Digital Research), and software applications and 'plug-compatible' hardware (encouraged from many firms). Key platform components were intentionally purchased from existing vendors, rather than developed in-house, so IBM could have all its components ready upon introduction.[33] The architecture was 'open' in a second, distinct sense. Any user could add third-party hardware or software components to an IBM-compatible PC. Eventually a great many firms would be able to make an IBM-compatible computer.

IBM's 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.[34] The number of platforms available to buyers decreased quickly, as one might expect when ESC shape market structure. Growth was rapid, as many other firms created complementary products for the IBM-sponsored platform.[35]

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

[33] IBM's PC division aimed to introduce their product within one year of deciding to enter. This was only possible with outside suppliers. See Chopsky and Leonsis [1988], Langlois and Robertson [1995], or Cringely [1994].

[34] This is the standard theory of IBM the 'strong second' succeeding commercially where others innovated. See, e.g., Davidow [1986] or Teece [1986] for similar summaries.

[35] By the mid 1980s the PC hardware revenue equalled mainframe hardware revenue, and exceeded it by the end of the decade.

This was the first competitive replacement of an established computing platform by another. The rarity of such an event illustrates the coincidence of several necessary circumstances. First, the entering platform's sponsor enjoyed a strong position within the industry, but outside the segment. Second, the entrant could introduce the new platform without undercutting its position in existing segments.[36] Third, the incumbent platforms were on the verge of an abrupt technical transition (in this case from 8-bit to 16-bit computing), which weakened the standards persistence associated with the established (8-bit) platforms. Fourth, the entering platform attained rapid technical advance, in no small part because of the sponsor's strategic choice for an open architecture and vertically disintegrated market structure.

Coincidences of circumstances like these do not arise frequently. The more typical experience, as we have pointed out, is platform persistence and continuity for old customers, while new platforms arise for new uses.

IV(ii). *The Mobility of Firm Capabilities, Reprise: IBM AS/400 Enters Superminicomputing*

As we noted in Sections III(i) and III(v), IBM had failed to establish dominant platforms in the technical minicomputer segment and in the business superminicomputer segment. By the late 1980s, IBM offered several incompatible systems intended for small businesses. Each platform had its adherents, but none was dominant nor was any compatible with IBM's mainframe products.[37]

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 'midrange' IBM product offerings.[38] However, the AS/400 offered greatly enhanced communication capabilities; a wide variety of new applications, available at product introduction, helped sell the product. IBM's Rochester division applied some of the lessons from the PC platform development, among others, to this market. It developed the AS/400 from hardware and software obtained from outside suppliers, distributed the platform through value-added resellers as well as its own sales force, and adopted a distribution structure designed to elicit rapid feedback from customers. The platform quickly developed the positive feedback associated with

[36] This relative lack of concern with cannibalization of existing product lines stands in sharp contrast with IBM's superminicomputer entry in the late 1970s. See Chopsky and Leonsis [1988] for the well-known story of how IBM set up a separate division to develop the PC, free of the delays associated with inter-divisional politics.

[37] Details on this somewhat controversial observation at Appendix Topic 37.

[38] The closest previous systems were the System 36 and 38.

ESC. The AS/400 has enabled IBM to become the largest superminicomputer vendor.[39]

Until the 1980s it was not clear whether superminicomputers were just small mainframes which had to maintain mainframe compatibility. By the late 1980s, however, the separateness (and 'non-IBMness') of the supermini segment was well-established. The success of the VAX platform had helped define the superminicomputer 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 (mainframe) business and the new one, IBM introduced the new platform with a vertically disintegrated production structure.

As was true of successful PC platform entry, the successful supermini platform entrant—which also happened to be produced by IBM—came from a strong firm within the industry. It also met a need for rapid technical advance, developing a structure for positive feedback around the platform.

IV(iii). *Divided Technical Leadership Yields Internal Entrants: From IBM PC to Wintel*

At the outset of the PC platform's existence, IBM played a strong role as the coordinator of decentralized technical progress by various component suppliers.[40] Later, this role slipped away to IBM's early partners, Intel and Microsoft. In retrospect, this shift was competitively disruptive and deserves close analysis.

In the mid 1980s, IBM possessed the advantage of being the leading seller of microcomputer hardware. This dominant position, backed by a strong brand name, let IBM promote the platform through 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 interoperate with IBM's.

Competition for control of the platform first arose in a combined vertical-horizontal form. An important upgrade to the microprocessor, the 80386 designed by Intel (a vertical supplier), was first used by Compaq (a horizontal competitor), not IBM, in a working computer system. The Intel-Compaq combination undermined IBM's claim that it steered the design of the platform. The new generation of PC was defined by the (Intel) chip inside, not the (IBM) design surrounding the chip, not least because of the rapid advances in processor speed driven by Intel. Other PC

[39] 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.

[40] See Appendix Topic 40 for discussion and references.

firms began to make 80386-based systems. The passage of control was reflected in the semantics of the platform's very name: it became known as the 'industry-standard,' not simply 'IBM-compatible,' PC. In this respect, the platform's sponsorship structure became similar to the earlier CP/M structure.[41]

As was true of previous platform challenges, IBM faced several strategic options. It attempted to regain control of the PC standard by connecting it to IBM-proprietary technology. The strategy employed three weakly connected innovations that together formed a new-generation PC (called the PS/2): a new hardware architecture (MCA), a new operating system (OS/2), and a local area network (LAN) protocol (Token Ring).

The strategy failed. The new operating system proved unreliable and only partially supported previously developed software applications. Although the PS/2 hardware was a step forward, it was a only a small step, especially for users who chose not to use the networking features. A committee of other PC hardware sellers proposed a less dramatic performance leap, and a greater emphasis on backward compatibility, with the 'Extended Industry Standard Architecture.' Customers and makers of 'plug-in' cards overwhelmingly chose the latter.

It was from this position of dramatically weakened control that IBM split with Microsoft over operating systems. OS/2 began as a joint venture between the two firms, and then split into two competing products, OS/2 from IBM and Windows from Microsoft. IBM entered a standards battle (over the operating system) without control of the hardware architecture and a promised, but much delayed, operating system product in development. In the event, Microsoft introduced a successful version of Windows (Version 3.0) before OS/2 could develop its own critical mass. The PC platform had a new leadership structure from which IBM was excluded.

IBM's strategic wisdom in waging a standards battle with a proprietary and backward-incompatible innovation has been second-guessed.[42] We deem it more important to emphasize general lessons about vertical competition. When different firms (potential platform leaders) share comparable technical skills and supply complementary components, the

[41] With hindsight, these events were foreshadowed by the internal disorganization associated with the introduction of an even earlier microprocessor, the 80286, as well as very early clone challenges to IBM's hardware. Contemporary observers did not attribute loss of control to any single managerial decision within IBM concerning the 80286. See Cringely [1992] or Carroll [1994]. IBM's loss of control was not recognized until the 80386 chip generation.

[42] Ferguson and Morris [1993], like many other analysts, look only at the PC market and argue strongly that IBM strategically blundered. In Section IV(iv), we offer an explanation of these events in light of wider IBM product strategy and a broader view of the industry's evolution.

allocation of technical leadership is arbitrary. When technical leadership is divided, it is quite difficult for a single firm to maintain leadership over a platform. A change in the conditions of platform leadership need not be very costly to the attacker since—from the user's vantage—the platform itself changes little. We note that the outcome of such vertical competition cannot be foreordained by each firm's initial position; the outcome of battles for platform control are sensitive to strategy as well as history. When technical leadership of a rapidly improving platform is divided among several firms, control of the platform can shift quickly, even within the span of one generation of new products.

IV(iv). *The Competitive Crash of the 1990s*

The early 1990s saw a new platform, 'client/server,' enter the mainframe and superminicomputer segments. The client/server platform departed from previous introductions; it was a 'platform of platforms,' in which an already existing platform (e.g., a workstation or minicomputer) was networked to highly intelligent terminals (PCs), which were themselves platforms.[43] The resulting destruction of rents earned by the earlier platform sponsors—IBM and DEC—marked a major change in equilibrium computer industry structure.

Our explanation of this dramatic change draws on the analytical elements from the preceding sections. A strong entrant platform emerged from outside the segment but from within the industry. The entry did not conflict with the existing product strategies of the mobile entrants. The incumbent platforms and their sponsor firms exhibited important technical and strategic weaknesses associated with long histories of continuous backward compatibility; the resulting inflexibility was unable to meet the new needs of long-time users. Finally, the new platforms were created in a technical regime where the appropriate organization of invention was divided technical leadership by vertically disintegrated firms, in which the traditional management strengths of the incumbents counted for less.

In the most common client/server arrangement, standard minicomputers or workstations act as 'servers' running database management systems or related software. PCs are the 'clients' that present information directly to users and may perform processing independently. Client/server applications responded to the greatest weakness of the established large-scale platforms, namely the difficulty of use for the ultimate demander of information processing service, the 'end user.' The essential

[43] 'Client/server' also describes specific (frequently sponsored) architectures, such as IBM's SNA and SAA, that implement the goals of the more informal definition that we employ in this section.

design concept called for development of large, complex applications, as powerful as mainframe software, but as easy to use as PC software. This concept required dividing existing applications into client and server portions.

Converting a PC, by now identified largely as a Wintel machine, into a client for office work did not prove costly at first, but it was not always easy. At many sites, a PC already ran (single-user) programs like spreadsheets, which could benefit from access to department- or company-wide data. Continuing to use Wintel PCs as clients preserved backward-compatible human capital. Significantly, it maintained the marketing connection between buyers and PC platform component sellers.

Server producers resembled earlier indirect entrants: They had improved their technical capabilities over the years in response to the needs of technical, rather than business, users. As these responses accumulated, workstations and minicomputers had developed hardware (but not the software) to perform many of the traditional functions of mainframes or superminicomputers (e.g., communication, file management, processor load allocation, etc.). The packaging of client and server, networked together, offered additional functionality, potentially at small incremental investment cost to the user. By offering a collection of individually backward-compatible products as a client/server 'solution,' sellers allayed many concerns about backward compatibility.

This process attracted firms with strong positions in pre-existing segments as participants in the client/server platform; a stunning variety of startup firms entered as well. Leadership initially was assumed by Microsoft, the dominant provider of operating systems for the client, and Oracle, the leading provider of database management software for the server.[44] At the time of writing, insufficient time has passed for ESC to determine a persistent market structure for this platform and its segments. There is also considerable competition for vertical control of the emerging platforms.[45]

IV(v). *IBM's Anticipation of Client/Server*

The largest incumbent mainframe seller, IBM, stood to be harmed the most by potential entry of an easier-to-use large-scale platform, perhaps built around the PC, which it no longer controlled. IBM recognized this threat and tried to reposition its own proprietary platform in anticipation

[44] Interestingly, the leading vendor of PC network software in the late 1980s, Novell, did not assume leadership.

[45] Appendix Topic 45 discusses the problem of 'sub-platforms' within the dominant platform.

(and later in response) to this threat.[46] In our opinion, the attempt failed more because of the changing conditions of competition, and less because of a failure in technical or marketing foresight.

IBM anticipated client/server in its company-wide product strategy, offering unified solutions for company-wide networked computing that drew on the strengths of both its PCs and larger systems. In particular, IBM's Systems Network Architecture (SNA) was intended to seamlessly connect computers of all sizes through a common network. It's Systems Application Architecture (SAA) was intended to support software applications development for all platforms (from mainframes to PCs). These offerings failed in the marketplace, for reasons we have already seen: The pieces of SNA and SAA that failed were the proprietary IBM PC technical initiatives of the late 1980s: the MCA bus, OS/2, and the Token Ring LAN. 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. 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 therefore depended on success in each segment. When IBM lost control of the PC platform, its proprietary client/server strategy was also destined to fail. The IBM networked-computer platform, embodied in SNA/SAA, never competed head to head against (what are now labeled) client/server platforms, for the components failed too soon. This failure is symptomatic of a larger shift in the forces determining market structure: Platforms that can vertically disintegrate will do so, quickly, if many firms have technical strengths which specialize in the different components.

IV(vi). *What Changed in the 1990s?*

The SNA/SAA strategy is an exemplar of the familiar IBM platform-coordinating strategy. The strategy had succeeded for more than 25 years—most of the industry's life—in the large systems segments. IBM has been unable to regain control of technical change in the large scale client/server platform, and no other platform steerer has emerged.[47] To

[46] 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] to perceive that IBM executives articulated the goals of client/server fairly early. Timely recognition of market trends was not the problem facing IBM; rather, it was the virtual impossibility of successful centralized control of a platform when divided technical leadership, among other forces, led to new roles for suppliers of particular technologies.

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

focus on IBM's apparent failures, however, misses the more general and important observations for the future of computer industry structure: All sellers attempting to control parts of the client/server standard are compelled by market forces to have at least partially open (non-proprietary) strategies. This is a radical shift in strategy in the 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 from other platforms. To steer the entire platform, a firm would have to make progress on each component at or near the technical level of the leader in that component. Speaking concretely, an aspiring client/server platform steerer 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 difficult feat, and it is no surprise (with the benefit of hindsight) that even IBM's attempt failed.

At the time of writing, several client/server platforms are competing for buyer acceptance. The theory of ESC and standards persistence from Section II strongly argues that the equilibrium market for 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. Section III also suggests that technological competition in the client/server market will likely be characterized by divided technical leadership and (vertical) competition for rents between component sellers within each platform. Our framework cannot predict the specific winning firms nor the technical details of the eventually dominant platform.

IV(vii). *Popular Theory: Superior Form for Organizations Revealed by Competition*

Our theory of platform competition explains why the computer industry, on the whole, has become more competitive, and why the dominant established firms could not prevent erosion of their rents. Our theory sharply contrasts with theories of incumbent firms as incompetently managed 'dinosaurs', a view which has been especially popular among technologists. The vertically integrated technology firm—IBM, DEC—is thought to be a slow inventor, while the specialized 'Silicon Valley'-style firm is focused and therefore a superior producer of new technology. The proffered story of competition between these organizational types simply holds that the new superior form triumphs over the old inferior one.

This Darwinian organizational story, while containing some attractive elements, is strikingly incomplete. The specialized computer component firm was not a brilliant organizational invention waiting to be discovered in the 1980s; such firms had been around in this industry since the 1960s. Instead, the market equilibrium of the entire computer industry shifted away from rewarding management and organizational skills associated with coordinating component innovation. Up to that time, IBM and DEC had incorporated specialists' inventions into their own proprietary platforms. The change in *vertical* competitive conditions, combined with the indirect entry of a new platform, devalued the coordinators' role.

The competitive crash of the 1990s surprised industry observers because they applied (erroneously, in our view) lessons tailored to strategy in individual market segments *without* considering the shift in competitive conditions underlying the industry's overall structure. For example, IBM played the aggressive entrant in several of the events that presaged the competitive crash (the AS400, the PC, the PS/2); thus it seemed that the firm was in fine shape. We interpret the various competitive events in that period as evidence that disruptive entry and structural change were growing easier, to the eventual *dis*advantage of IBM.

V. CONCLUSION: CHANGE AND CONTINUITY IN MARKET STRUCTURE

We conclude by integrating our analysis of (i) the forces leading to concentration and persistence within industry segments and (ii) platform entry into a unified explanation of computer industry technological competition in the past 35 years. Rapid technological change has been one, but only one, feature of this industry. Buyer-seller relationships and divided technical leadership, to name only two others, have also played a large role in determining the matching of platforms with uses, the identity of successful suppliers, and the organization of the computer industry.

V(i). *Change and Continuity*

Any analysis of computer industry structure must explain a mixture of rapid change and long term stasis.

1. Computer use has grown dramatically. At the intensive margin, quality has increased, and price decreased, for existing computer types ('price/performance has improved exponentially,' in industry jargon). At the extensive margin, new types of computers have been invented.
2. Dominant platforms have persisted for decades in the main industry segments. The organization of supply in these segments remained stable for much of the decade of the 1980s.

3. 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.
4. Some striking elements of continuity persist in industry structure. First, only a few platforms serve most uses at any one time. Second, most uses are still served by platforms updated through generations of backward-compatible improvement.

Our explanation for these phenomena 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(ii). *Ongoing Technological Opportunity and the Forces for Stasis*

Technological opportunities in the computer industry have constantly expanded. These opportunities have been realized by (i) steadily improving the computer hardware and software in computer platforms offered to already-recognized groups of demanders and (ii) occasionally inventing new platforms, or re-inventing old platforms, to serve an entirely new body of demand. We explain this tendency for buyer-seller relationships to remain unchanged, despite technological competition at two distinct margins.

V(iia). *Continuity within Segment*

We notice a common phenomenon that has arisen across all platforms: Rapid technical change within each segment respects backward compatibility, because buyers' relationships with platforms are very long-lived, as are marketing relationships between buyers and sellers. Within-segment persistence follow the same economic forces that explain segment-level concentration. Buyers' and sellers' investment in platform-specific assets lead both parties to respond to ESC and standards persistence at the platform level. Mutual investment between buyers and sellers was the key to the invention of the platform. Segments with business buyers, where these forces are particularly strong, tended 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, have occurred only infrequently.

Importantly, our explanation of within-segment platform persistence does not require a single platform sponsor. In the client/server era, we have observed concentration and persistence with multiple sellers and with divided technical leadership. These decentralized platforms do not vitiate our story because ESC theory and the platform persistence theory are robust. The implications of the theory we use do not depend on the specific industrial organization of supply or on the ownership structure of the asset leading to platform persistence.

Looking ahead, we believe that the basic forces of ESC and platform persistence still underlie the industry's structure. More specifically, we predict that, with the advent of the networked computing platform in the 1990s, concentration and persistence of platforms will re-emerge. We are confident in this prediction because (i) the demand-side forces behind it are as strong as ever and (ii) it assumes very little about the specific nature of supply, because of our theory's robustness.

V(iib). *Change: Opening Up New Markets by Non-disruptive Platform Entry*

We note two empirical regularities pertaining to the development of new segments. First, completely new platforms flee competition to serve new kinds of needs. Second, the same engineering capabilities serve technical customers at first and then, with suitable reformulation of software and marketing capabilities, business customers. Our analysis of these regularities explains them in terms of powerful forces for stasis in computer industry structure which were allied with a slowly-growing loophole, a nascent force for change.

Steadily expanding technological opportunity underlies the matching of platforms to uses. Engineering only creates new kinds of computer *components*—hardware, software, and networks—but a *platform* is a more complex creature of engineering *and* buyer-seller interaction. Young platforms, lacking an installed base of users and wide varieties of complementary product suppliers, have systematically succeeded more often in segments for which historical marketing relationships were less operative. In particular, a new platform tends to succeed commercially if it initially avoids competing with an existing platform, to allow time to build complementary assets and buyer relationships (and, in some cases, to 'shake down' (resolve) technical problems). As a consequence, new platforms serve new uses.

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

V(iii). *Disruptive Platform Entry and Shifting Vertical Control*

Violations of these empirical regularities do not contradict the theory; we think the exceptions improve the rule. However, they caution us to take a careful look at the broader industry dynamics.

V(iiia). *More Disruptive Platform Entry over Time*

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—share a common feature. In both instances, the new platform had already partially matured in another segment. Critically, the maturation involved market connections as well as technical progress. The resulting marketing 'head start' formed the basis for successful entry by the platform, especially in its early period.

It would be unwise to read these incidents as a trend *away* from platform concentration and persistence within segments. The forces toward those outcomes are still in place. Instead, they reveal a changing relationship between market structure equilibrium in individual segments as the entire computer industry grew. We label these changes 'disruptive' because they signify the collapse of long-standing segment boundaries. Competition with the pre-existing platform came from outside the individual segment. Indirect entry into existing segments by sellers in other segments has become more frequent because of changes in the overall industry, but has been attenuated because of the still-considerable boundaries within any particular segment.

V(iiib). *Vertical Competition and Standards Stealing*

Our explanation also examines the changing control of the standards in what used to be called the IBM PC. In this case, 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 being dominant. Once again, we observe an important change in strategic interactions among *firms* despite continuity in market outcomes at the *platform* level.

We think it notable that platform continuity within the segment persisted, even as the leadership structure changed. Industry-wide change, especially the appearance of specialized entrants with greater (componentwise) capabilities, led to divided technical leadership in the segment. Divided technical leadership offered the possibility for shifts in control of the standard from one leader to another. As a client/server platform (or some other networked computing platform) becomes important, it will be interesting to see how standard-setting strategies change over time. We offer no prediction on this point, since competition to control standards is such a new feature of many industry segments. We can say that the struggle for control of standards among firms selling interoperable products, made possible by divided technical leadership, will be the locus of much future 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(iv). *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. In this article, we examine the long-run dynamics in this industry, from which we draw two relevant trends. First, vertical disintegration in supply has been increasing. Second, the technical and market capabilities have broadened in many kinds of firms and in many segments. Both trends have occurred for reasons only loosely connected to their eventual influence on competitive outcomes, which acquired inevitability only in hindsight.

Very powerful forces led to platform dominance within different segments. Foundings involved (initially) weak entrants avoiding competition in established segments. The extension of existing (somewhat stronger) platforms to new uses in new segments also avoided competition with existing platforms. Incumbents were constrained from meeting these potential competitors directly because of the need to maintain backward compatibility for existing customers. As users in a segment grew more diverse, a single platform failed to meet all their needs. Indeed, IBM achieved success in the microcomputer and minicomputer segments only when it entered with platforms that were distinct from its mainframe offerings. It is hard for us to imagine that an incumbent could have succeeded any better in a wider variety of segments than did IBM.

Platforms with divided technical leadership are distinct from sponsored platforms. They differ along three mutually reinforcing dimensions: speed of innovation, degree of vertical disintegration, and the degree of specialization of individual firms. In a concerted departure from prior practice, IBM placed great weight on speed of development when it entered microcomputing in 1981. Vertical disintegration within the microcomputer platform was IBM's choice. It made this choice because it saw this as the only way to establish a new platform against existing and rapidly advancing platforms. In retrospect, a more prescient firm might have chosen something more integrated; however, we think the attempt would have failed to stop the tendency towards vertical disintegration. Divided technical leadership originated in the PC and workstation segment and was starting to arise in the form of third-party software and peripheral component markets in other segments. It could not have been delayed for long by even the most brilliant incumbent.

The computing industry today exists in the environment that was only emerging at that time. The move to a new industry equilibrium—characterized by rapid changes initiated by specialized, vertically disintegrated firms—devalued platform-steering expertise, the traditional strength of IBM (and its minicomputer counterpart, DEC). This devaluation would have occurred had IBM not entered the industry and it still occurred in spite of IBM's entry. It appears to be permanent.

V(v). *Implications for Competition Theory*

We have taken a market-equilibrium perspective to explain switches between structural stability and disruption in the computer industry from the mid-1960s to the present. We argue that the same forces have been in place throughout the industry's history. To see these switches over time and across segments demands a careful positive analysis with a wide scope. Our analysis necessarily skips many details, using secondary sources for corroborative evidence. Historical accounts have 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 attempt to fill the gap between the historical and the analytical.

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. We have identified two gaps. The first is the theory of indirect entry. Our observations point to historical links between market structure in the individual segment and the broader industry equilibrium, and to analytical links between organizational theory and competition theory. Indirect entry takes time because the entity (firm or platform) that competes must first mature; the competitive strategy which can be used to exploit, and to defend against, this mechanism is not very well-developed. The second gap in theory relates to divided technical leadership and vertical competition. Our observations suggest a new vector of entry threats to established positions, coming from sellers of complements, not substitutes. They also point to a new kind of link between the vertical organization of supply and the degree of competition for rents. We, at least, are not surprised that an industry as inventive and important as computing offers these new challenges regarding the analysis of industry structure and of competition.

ACCEPTED JULY 1998

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