2

The Value of Competitive Innovation and U.S. Policy toward the Computer Industry

Timothy F. Bresnahan and Franco Malerba

2.1 Introduction

The United States has maintained a position of international leadership in the computer industry during the last fifty years despite considerable change in markets and technologies. The firms, entry conditions, and firm structures that supported U.S. success in the IBM era bear little resemblance to those of the Silicon Valley era. Persistent U.S. international leadership poses a challenge to economic analysis: Is it just a coincidence that the United States led in two such different industrial contexts? Or are the two industrial contexts simply much more similar than they appear, so there is no change? In this chapter, we provide an analysis that explains both the changes in markets and technologies and the persistence of U.S. international leadership. We take up two related themes about the ongoing international success of the computer industry in the United States and its ongoing ability to supply new technologies to support economic growth: (1) the factors at the base of the concentration of rent generation in a single country and their persistency over time, and (2) the institutions and public policy forces contributing to this concentration in a country. Both themes cover a history of some fifty years, leading up to the conflict and policy questions of today.

First, we ask what industry forces have led to the concentrated location of rent-generating supply[1] in this industry in a single country, and what forces have selected the United States for persistent success. The concentration question has a reasonably direct answer arising from the application of industrial organization methods to international trade. Readily identifiable strategic and technical forces lead to an equilibrium industry structure in which, for many important technologies in the industry, there is a high level of concentration. This is especially true of the parts of the industry where invention and technical progress are sources of private and social rents. Ongoing technical and market progress over many decades means that those forces have not waned.

Explaining the persistence of producer rents in one country is far more difficult. There has been dramatic change in the economic and technological basis for the rent-generating parts of the industry. To be sure, the industry has periods within which a firm or a technology persists in a leading position because of first-mover advantages related to lock in and network effects. Over the longer haul, however, those positions have often been eroded and replaced. The market and technical positions that led to early U.S. success have been eclipsed, and the firms leading the industry in rent generation have changed several times, not only in name, but also in fundamental organizational structure, technical competence, and marketing capability. Persistence in the United States over the long haul is not explained by the ongoing success of any particular national champion firm or technology but rather by the replacement of one by the next. This is closely related to the industry's ability to bring forth new technologies that support new applications of computing, a growth pole for the world.

Second, we also address the related question of national forces outside the industry that contribute to the location of the rent generating sectors or to their persistence. We include here a range of national institutions, such as scientific and engineering development in universities, creation of high-tech labor forces, and so on, but focus particularly on the role of public policy. The role of institutions and public policy has been supportive rather than directive or determinative of private-sector efforts within the industry itself. Critically, institutions and policies have not been aimed at preserving the rents of the industry from one period to the next. Instead, they have been focused on supporting the creation and market selection of new capabilities. Public policy has avoided the mistake, widespread among the rich countries in connection to this industry, of protectionist national champion policies. These slow the loss of position in one era but do not encourage winning of a new position in the next one. Second, U.S. institutions and policies accommodate the market forces behind long-run change, thus linking U.S. producer rents to the best prospects for the future rather than the past.

This long-standing policy stance of the United States is little understood, so that when it makes the headlines, as it has in connection with the Microsoft antitrust case (*U.S. v. Microsoft* and *State of New York et al. v. Microsoft*), it sets off a new round of debate over whether the United States should become protectionist of existing producer rents. In fact, the U.S. government and existing national champion Microsoft are in conflict in an antitrust suit. The government does not seek to protect existing rents but instead to protect potential competition based in new technologies that might disturb the status quo.[2] This is a continuation of the long-standing policy of enabling market choice of new rents rather than protecting old ones, a policy that has led to ongoing improvements in the technical and market basis of computing with substantial social benefits, and incidentally to the continued location of the producer rents in the United States.

In this chapter we examine the forces leading to concentration and persistence of supplier rents at two time scales. One is within particular technological eras and within particular industry segments, such as the time period in which the most important computers were mainframe computers. For this time scale, analysis based on the new trade theory works very well. Our other time scale is long enough to capture the foundation of new segments, such as the personal computer segment, and transitions in the industry, such as the emergence of competitors against IBM based on new technologies. At this longer time scale, we need an entirely different body of theory to explain producer rents persistently concentrated in the United States.

2.2 Short- and Long-Scale History: Persistence across Distinct Technological Eras

In this section, we examine the forces that have led to the concentration and persistence of the rent-generating parts of the computer industry as it has transitioned through a number of distinct eras: mainframe, minicomputer, PC, supermini and client-server computing, and the Internet. *Within* each of these eras, we illustrate the forces supporting the ongoing creation of social rents and persistence of the location and success of industry, involving the improvement of existing technical, marketing, and industrial organization capabilities. Since there are powerful forces for national persistence within each era, the persistence evident in the long time-scale history arises in the forces behind industry location at the *founding* of each era. Thus, we provide a short analysis of each of those era-founding moments and of the related periods of *transition* between one era and its replacement.

2.2.1 Persistence of Leadership in Business Data Processing; Mainframes and IBM's Leadership

Mainframe computers are systems used for large departmental or company-wide applications. The demanders are professionalized computer specialists in large organizations. They have close bilateral working relationships with suppliers. In the industrialized countries, many of the sites doing this kind of computing have been in operation for decades. A process of learning by using, plus ever cheaper large computers, has led valuable applications and a steadily rising demand curve. These sites have absorbed—and paid for—dramatic increases in computer power. While mainframe computing sites number only in the tens of thousands, their total market demand has been on the order of billions of dollars over several decades.[3]

Mainframes are produced by vertically integrated firms. IBM is the largest producer, active in the development, manufacturing, marketing and distribution of its systems, and producing most of the components in-house. Market success was related to major and continuous R&D efforts, to effective marketing, and to the close integration of technology, marketing and management. One element of IBM's strategy was particularly important. This was the development in 1964, of the computer *platform*, and the related technological concept of compatibility standards and modular (interchangeable) components.[4]

IBM controlled and coordinated system development, even in the presence of rivalry from the producers of some modular components, because it could control key interfaces. Other firms could sell hardware or software add-on products compatible with IBM systems, but only if they used interfaces defined by IBM. Compatibility across products and over subsequent product families allowed the persistence of existing standards and lock-in of the existing customer base. IBM's long-standing dominant position in the mainframe market was heavily reinforced by positive feedback forces associated with the investments by other firms, by suppliers, and by customers in IBM platforms.

Technologies, firms' capabilities, strategies and organization, customers' needs, and market structure were strikingly IBM-centric. Competitors, customers, and even national governments defined their computer strategies in relationship to IBM. For decades, IBM was the manager of both the cumulative and the disruptive/radical parts of technical change. When an established technology aged, IBM was not only its owner but also the innovator of the new, a process by which some of the sunk costs of the industry were destroyed by being replaced.[5] But other sunk costs—such as the interfaces and compatibility standards at the heart of IBM's product lines, IBM's investments in customer relationships, and customer's investments in technical and marketing relationships with IBM—were preserved. As a result, IBM and U.S. rents persisted until the 1990s.[6]

The concentration of the mainframe segment and the persistent leading position of IBM—and the United States—are attractive places to use new trade theory arguments.[7] There were very substantial *scale economies* at the firm level, not only technical, but also Chandlerian ones surrounding joint investments in management, marketing, and technology. Furthermore, the nature of compatibility and platforms meant that there were social scale economies as well. The social scale economies, especially, were associated with sunk costs by buyers. These forces are powerful reasons, as modern theory makes clear, for concentration and persistence.[8] Even as the market segment grew dramatically in size, the scale economies continued to be large relative to demand and were appropriated at the firm level.[9] Any equilibrium theory of industry structure will predict such a result, though predictions about which firm (or even which kind of firm) earn rents may well depend on delicate and hard-to-observe strategic opportunities.

Thus, the international allocation of producer rents will inherit the structure of the underlying industry equilibrium. The rents flow to one country, the one containing the rent-earning firm.

There is no connection between this outcome and any affirmative strategic trade or industrial policy. Throughout the period of IBM's dominance, the United States opposed the dominant status of its own "national champion." The height of this opposition came in the long antitrust case, *U.S. v. IBM*, with a number of arguments, including those contending that IBM's vertically integrated structure prevented competition in component markets. The case ultimately was dropped by the government.[10]

Non-U.S. national governments protected their domestic producers against IBM, with the hope of building an industry that would earn rents. This met with no success under European "national champions" policies and modest success under Japanese managed competition policies.[11] Japanese firms such as Hitachi sold IBM-compatible hardware in the unbundled regime. There was, however, no serious direct challenge to IBM's standard-setting position in mainframes either at home or abroad.

2.2.2 Original Location of the Industry: The Founding of the Computer Industry

With increasing returns to scale as strong as those in mainframe computing, the underlying industry equilibrium is indeterminate with regards to which among several firms will dominate. The international allocation of producer rents is indeterminate. As a matter of pure logic, this raises the possibility of governments engaging in strategic trade policy to steer the producer rents to their countries. Given the persistence of leadership positions, the same logic suggests that governments will (or should, in the more mercantilist variants of the theory) engage in strategic trade policy activities at the beginning of an era, when the market allocation is being determined.[12]

That theoretical logic, however, bears little resemblance to the forces and events determining the international allocation of rents in the period leading up to the establishment of IBM's position of dominance (roughly from late in World War II to the mid-1950s). That calls for a very different view of planned or unplanned outcomes of government action.

To be sure, it was not predetermined that the producer rents to the early computer business would go to the United States. Many of the early computer companies were founded by entrepreneurs from universities, and during the 1940s and early 1950s universities in the United Kingdom and France as well as the United States did advance research and built early computer prototypes. Additionally, European firms such as Siemens, Bull, Olivetti, BTM, Telefunken, and Zuse had computer projects, some with a heavy commitment to R&D and others with strong connections to business customers. A similar list emerged in the United States, drawn both from existing electronics firms and entrepreneurial startups. Both technical and market capabilities were built on both sides of the Atlantic.[13]

There were powerful reasons why the equilibrium would flow to a U.S. firm. It was a country with a large demand curve for computers and, for national defense reasons, a steep one. The various U.S. defense department agencies funding much computer research, and buying much in the way of early computing, were quite nationalistic. Finally, right after the end of the World War II, Japan was far from technically advanced, and Europe more oriented to rebuilding existing areas of strength than to building in a new one.

All these differences do little to help understand the actual sources of U.S. success, which occurred far more at the level of the firm than the country. An English IBM, for example, could easily have emerged and won.[14] Explaining our certainly of that counterfactual involves delving a bit deeper into the reasons for IBM's success and the limited role of its U.S. location.

In the late 1940s and early 1950s, there was considerable uncertainty about the technical features of computers, their highest-value uses, and the appropriate structure for a computer company. A number of different computer companies, in a number of different countries, made very distinct choices about technology, market, and structure. IBM emerged from this early competitive epoch to dominate supply, in the process determining the technologies needed for computing, the marketing capabilities needed to make computers commercially useful, and the management structures that could link technology and its use. The United States was, in the ensuing era, the dominant country in the computer business because it contained the dominant firm, IBM.

Much of what is ex post obvious about the mainframe segment was ex ante difficult to foresee.[15] In the late 1940s the obvious application of the computer was for rapid calculation for scientific or military purposes. Forecasts of the future of the computer as a business data processing machine were far vaguer. With so much uncertainty, there was considerable opportunity for experimentation and error. The firms competing for market leadership ranged from those with strong electronics technical capabilities (some of these were startups) to those with existing market connections to business customers. By far the most common experiments, however, were based on the view that the computer would be used for computation, namely, rapid calculation. These experiments pushed firms away from the largest and most profitable uses of computers, business data processing. Some firms with strong connection to business equipment customers did attempt to adapt to the new circumstances; for them the challenge was one of mastering a major change in technical basis, from mechanical or electromechanical to electronic.

IBM, a preexisting business equipment firm, was dominant in the tab-card business in the United States in the era before the computer and thus had, already, a strong marketing connection in business data processing. IBM was able to adapt to new circumstances by building a substantial electronics technical capability and a capability to manage the connections between technical progress and customer needs.[16] It was this construction of an integrated technology, marketing, and management company (the famous Chandlerian three-pronged investment) that permitted IBM to dominate the industry. In addition, IBM's preexisting knowledge as a business equipment company led it to experiments that were ultimately consistent with the new emerging demand. Out of literally dozens of experiments with the appropriate model of the firm, IBM's adaptation of its market knowledge, combined with technical experimentation, ultimately succeeded.

The key role of decision making at the firm level does not mean that the national-level forces were unimportant, only that they played subsidiary roles. Indeed, the intense firm-level experimentation in the United States was supported by national institutions. Many experiments came out of entrepreneurs in universities. Experimentation, especially technical experimentation, was supported by a very large number of different government computer technology initiatives. Uncertainty about future technologies and new demand raises the returns to a variety of experimental, exploratory approaches.[17] Mutually exclusive approaches to a certain objective have, collectively, a higher probability of success than does any one.[18] In addition, when the nature of demand and the direction of technical change are uncertain, there is a breadth effect of pursuing distinct technological objectives.[19] When uncertainty relates to demand and commercialization as well as to technology, the range of experimentation is not limited to technical opportunities but includes organizational forms and modes of buyer-seller interaction. In general, the less demand and technology are defined ex ante, the wider is the variety of approaches that firms within an industry pursue in order to reach a successful new product, technology, or process.

The U.S. policy was fundamentally consistent with this view of the value of experimentation and exploration. The government-sponsored research initiatives were not particularly to the advantage of IBM.[20] Nor did government initiatives set a technical direction. Rather, government R&D funding and defense procurement served to support exploratory activities and the development of a wide variety of firms and technologies.

Far from picking IBM as a leader, the U.S. government supported variety.

U.S. market institutions then worked to let IBM emerge as the clear industry leader.[21] This selection mechanism was not present in other countries: European countries used national champion policies that protected one large national firm in each country, weakening selection processes. In general, in the United States the role of successful national institutions and especially successful national policy was to support a wide range of initiatives, one of which eventually worked out in the marketplace. The motivation behind the support was not one of directing rents toward the United States, but rather of supporting valuable basic research and, distinctly, mission-oriented defense procurement.[22]

By their trial-and-error nature, firm-level experiments and exploration lead to shakeouts. In general in high-tech industries, radical innovations and emerging markets are often followed by shakeouts that not only reduce the number but also the variety of firms. The role of a shakeout is to *select* among the variety of technologies, organizational forms, and modes of buyer-seller interaction that were early experiments.[23] Of course, the intensity and rapidity of selection depends upon a range of factors. Barriers to exit, whether as a matter of government policy or the nature of competition, slow selection. Competitive environments speed up selection.

U.S. policy at the beginning of the commercial computer era was consistent with the idea that rapid selection by markets is likely to do a better job than selection directed by governments or slowed by them. The result of supporting a wide variety of initiatives, but permitting market selection rather than strategically directing the industry, was the emergence of a firm with technologies and structures aligned with commercial market desires. This was the key to the long process of computerizing white-collar work, first in the United States and later in all the rich countries, first in the service sectors then in most of the economy. This computerization of work led to substantial technical progress in the using industries, ultimately a significant contributor to world economic growth.

2.2.3 The Minicomputer Segment: Concentration with a Different Cause

Though IBM was dominant in mainframes selling to corporations, other computer demand segments emerged and grew. New computer systems and distinct sellers supplied these.

One new kind of system—*minicomputers*—was for *scientific and engineering demand and other technical computation*. Minicomputer users are factories, laboratories, and design centers. These were technically sophisticated customers.[24] Programs are written for a single use; the value of compatibility (as opposed to technical power) is correspondingly less. Thus, minicomputer firms compete less by sales forces, marketing, and support and more by technical progress. Sellers tend to use technical rather than businesspeople to visit customers, and to have good communications with customers about the best technical features of the computers. Information about the technical features buyers wanted and the technical capabilities of different sellers' products flowed freely. Minicomputers shared only the most basic technologies with mainframes.

Multiple minicomputer platforms flourished, with partial compatibility.[25] Initial firms were entrepreneurial start-ups (primarily technology based) such as DEC, Perkins-Elmer, and Gould. Most were clustered in the Route 128 region near Boston. Entry barriers were never high enough to keep out well-funded and technically capable entrants: Hewlett Packard entered successfully well after the category was established. Despite open entry conditions, DEC maintained market share leadership, relying on continuous technical improvements.

These American minicomputer sellers were international leaders, especially DEC. Consistent with the multiple-seller industry structure, some European firms entered and a few even earned rents for a period. For example, during the 1960s and the 1970s in Germany several firms, such as Nixdorf, Konstanz, Triumph Adler, Kienzle, Dietz, and Krantz, started to produce minicomputer systems. These minicomputer systems were all proprietary, focused on sector-specific applications and had specific software. These companies (particularly Nixdorf) experienced success until the 1980s but later exited.

Why this pattern? The underlying industry structure was one of monopolistic competition with multiple competing firms, compatibility standards, and platforms. While it was concentrated, barriers to entry were far less than in business computing segments. Scale economies were driven primarily by R&D, not particularly by marketing or by network effects. The comparatively limited role of user platform-specific investments meant less opportunity to create a dominant position by establishing marketwide standards. These modest scale economies and modest sunk costs led to a monopolistically competitive structure, and not one that yielded nearly as much producer rent as did the mainframe segment.

Accordingly, the minicomputer segment first went through a period of some geographical distribution and then later grew more concentrated in one country. This time, however, the concentration in one country was not so much in one firm. Instead, spillouts across multiple producers who continued in competition characterized the industry.

2.2.4 Forces Favoring the United States in Minicomputers

The preceding market structure analysis leaves open the question of why the minicomputer industry, too, ended up specifically in the United States. The first obvious cause to consider is that the existence of a U.S. dominant firm in the immediately preceding technology, mainframes, was an important cause of continued U.S. dominance. This turns out to be false, as does a story of purposeful government rent steering.

The existence of a very different body of demand permitted emergence of a distinct segment without competition from the existing dominant computer technologies, mainframes. Since the minicomputer draws on distinct technologies and serves very different demands, and since the marketing model for minicomputers is very different and the typical organization of a minicomputer firm is quite distinct from a mainframe one, it is not surprising that there was some segmentation.

It is perhaps more surprising that IBM, the firm, was unable to dominate this segment even as it effectively dominated (and unified) all the segments with commercial buyers. Adaptation of IBM's capabilities to the distinct conditions appears to have been quite difficult. The struggles of existing dominant firms to adapt to radical change is a familiar topic,[26] of course, and the incentives for IBM to adapt to this particular change were quite low at the founding stage since it was already posed to dominate a more profitable segment. Despite a series of efforts to enter, and despite the low barriers to entry, IBM was not one of the leaders of the minicomputer segment.[27]

A variety of forces far weaker than continuity by a successful dominant firm located the minicomputer industry primarily in the United States. The technical computing research sponsored by the defense department, mentioned earlier, led to early minicomputer companies related to university research.

Institutions supporting formation of a technology firm were particularly strong in the United States. Yet there were a substantial number of European entrants (not all coming from national champions). Finally, some of the skilled workforce and technical knowledge, but only some, was shared with mainframes. This was a (weak) force for co-location of minicomputer rents with IBM in the United States.

Ultimately, however, the location of the minicomputer industry in the United States was the outcome of the same set of forces of experimentation and exploration[28] followed by market selection[29] as we saw in mainframes. The market selected a very different set of technologies and organizational forms in this segment, so the U.S. policy of favoring a wide range of initiatives rather than existing national champions was congruent with underlying market and technical forces. This opened up the possibility for ongoing variety in the choice of technologies and the direction of technical progress within the broad computer industry, as invention in two distinct segments went forward. That variety would ultimately contribute considerably to the ability of the overall industry to growth.

One should not exaggerate the distinction between government-led and market-led outcomes in the minicomputer segment, for they are far closer here than in the mainframe segment. Military demanders wanted much the same from minicomputers as did other technical demanders, and government engineers were among those advancing such technologies as the UNIX operating system and the ARPAnet (later Internet) networking environment. The distinction to draw here is between military procurement that is purposively a part of strategic trade policy, which does not describe the U.S. stance accurately, and mission-oriented military procurement that raises the demand curve for valuable technologies, which does.

2.2.5 Concentration and Persistence in PCs

A third kind of computer systems—*personal computers* (PCs)—was for "individual productivity applications." This newer demand segment opened up in the 1970s. The customers are again distinct from the previous two segments, as are the basic technologies of hardware and software. Powerful network effects link customers directly to one another and to vendors. These network effects have been an important source of concentration and persistence; the structure has typically been of a worldwide dominant platform, sometimes with a strong second. Since the early 1980s, there has been persistence of the IBM PC platform and its descendants in a chain of compatibility. Over that same period, the typical customer has been nontechnical, so that marketing capabilities have played an important role.

These distinctions from the preexisting mainframe and minicomputer segments permitted emergence of a new set of technologies, firms, and markets, only loosely linked to prior sources of rents at the national level. The PC segment also has important differences in industrial organization, of which the most important is vertical disintegration of supply of key platform components, which leads to divided technical leadership (Bresnahan and Greenstein 1999). The primary advantages to sellers of divided technical leadership are speed and specialization, and the PC segment reflects that. Product life cycles are very short, and the rate of change, upgrading, and improvement in hardware and software has been high. Complex systems products could be quickly brought to market because specialists innovated rapidly.[30] Divided technical leadership supports this by permitting advances in one part of a platform—say, a specific piece of platform software, like an operating system—by a specialized firm while other sellers of other forms of key platform software and hardware advance at their own pace. An advantage to buyers, but not particularly to sellers, of this industrial organization is that it is more competitive than vertical integration of key platform components.

In each horizontal layer (component market) of the PC segment, market structure was highly fragmented at the beginning, often becoming more and more concentrated as time passed. Some key components had dominant firms: microprocessor (Intel), operating system (Microsoft), and word processor (WordPerfect and later Microsoft). Other key components were supplied much more competitively (e.g., many hardware components such as add-in cards). The making of the computers themselves became highly concentrated shortly after the introduction of the IBM PC, but new entrants eroded that position later on.

Again, the American suppliers became the world leaders, though there were real efforts, both government-sponsored and private, to move leadership to Europe or Japan.[31] Understanding persistence and concentration in the United States is at once easy and hard.

The easy part is the explanation of the high level of concentration and persistence in platforms. Products with large-scale economies and much cumulativeness, such as word processors, operating systems, and microprocessors, show concentration and persistence of the industry leaders at an intermediate time scale. Shifts in platform leadership from one firm to another, however, open up a gap between persistence at the firm level and at the national level, a topic to which we will return later. A strong force working at the national level (but not the firm level) is close vertical linkages among distinct firms. To some degree, this is accomplished by the regional co-location of competitors and complementors, notably in Silicon Valley. Thus, the concentration of the key rent-generating components in the United States reflects many of the same forces present in minicomputing, including a shared skilled-labor pool, a shared body of technical knowledge, and other externalities across firms but within region.

While the PC segment in its early stages shared important technologies with minicomputers (CP/M closely resembled a minicomputer operating system) and briefly shared a dominant firm (IBM) with mainframes, both technological and demand developments were largely separate from those in the other segments of the industry. Even the regional agglomeration economies were distinct, illustrated by the shift from Route 128 to Silicon Valley.

The success of Route 128 in one era and Silicon Valley in another led to number of European imitations, often with considerable government support. Of these, there is only one that can even be called a partial success, the area around Cambridge (U.K.). However, this area never developed a position of world market leadership. Often the European attempts were top-down and directive, and many involved the still-surviving national champions.

Another advantage of divided technical leadership is that it has permitted relocation of supply of some platform components to other countries. In Taiwan, a government-supported "Silicon Valley" has flourished, with agglomeration economies, local positive externalities, and so on. Taiwanese policy has been as far from "national champions" as imaginable, being quite tolerant of entry and exit.[32] While successful, the Taiwanese cluster is not in competition with the U.S. one, confined to hardware and components now in the later stages of the product life cycle.[33]

But now let us turn to the more difficult part of explaining the persistent U.S. position that is, once again, understanding why a persistent and concentrated structure was located in a particular country. For the PC segment, this problem is exacerbated by lack of continuity at the firm level even within the segment. We examine three periods of rapid and disruptive change, the initial founding of the segment (mentioned earlier), a platform shift, and a change in platform leadership.

The rent-generating parts of the PC industry have always been American, but there are three very distinct times in which leadership of the industry has emerged or shifted. Each time the forces that tended to locate the rents that then persisted in the United States have been distinct. They have never involved direct government rent-steering, though a number of distinct mechanisms for encouraging innovation have been in play.

2.2.5.1 Original Founding of Hobbyist PC Segment At the beginning of the PC segment, there was experimentation and exploration with several prototypes by a large variety of hobbyists, and later on with systems and software developed around two de facto standards: CP/M and Apple II. Here again a variety of new specialized microcomputer firms such as Apple, Commodore, Digital Research, and Tandy explored new developments in microcomputers. This experimentation and exploration was worldwide, but the most successful firms emerged in the western regions of the United States.

There were some very limited elements of continuity from the previous successes at a national level. PC software and hardware took important ideas from minicomputer products, for example. Yet this flowed through a loose network of technically sophisticated people rather than as a continuation of the commercial success of the preexisting computer industry.

Adaptation to the new market segment by existing computer firms was not an important source of supply.[34] Other firms, such as microprocessor manufacturers Intel and Motorola, did "adapt," though their adaptation consisted largely, at this stage, of selling existing product lines to new customers.

The most important U.S. national institutions and policies supporting the emergence at this time were entirely non-directive: the existence of a large body of technical expertise in universities and the generally supportive environment for new firm formation in the United States. The location of the initial PC hobbyist industry—not one associated with a large volume of rents—in the United States was largely because technology entrepreneurship in broad generality was easy there. Persistence in the short run occurred because the network effects surrounding early standards and associated sunk costs were strong.

Experimentation in Europe was rather more limited in this era and in the era of the IBM PC. Most entrants were established electronics firms, including the long-protected national champion computer firms. (An exception occurs in the U.K., where there were some entrepreneurial efforts.) Japanese efforts in the PC era notably involved an attempt to use the country's cultural and linguistic uniqueness to start a local cycle of network effects, an effort ultimately defeated by worldwide scale economies. In neither case were there effective mechanisms for protection for, in contrast to the mainframe era, PC buyers were small, scattered, and unlikely to respond to government jawboning.

2.2.5.2 Creation of the IBM PC Up to this point, we have discussed market segment foundings periods of rapid technical change during which the location of rents in a particular country is still open to determination, not fixed by first-mover advantages. We now turn to a series of *transitions*, similar time periods during which the rents in an existing segment shifted from one firm to another, often from one type of firm to another. The first of these is the creation of the IBM PC.

After a brief period, it became clear that the highest value uses of the PC were not for hobbyists but instead for such business applications as word processing and spreadsheets. The marketing model of the early PC industry was not optimized to that purpose, and discontinuous technical progress meant an opportunity to replace the existing technical standards.

IBM, the existing dominant firm in commercial computing in the United States, saw the nascent personal computer market in two very different ways, one linked to its existing base of customers and flow of rents and the other as completely separate. After a debate inside the company, in the early 1980s the firm entered the PC business, taking advantage of its strong capabilities as a marketer of computers but in a way that was completely separate from its existing franchise.[35] Leadership of the PC segment quickly passed to IBM, though Apple computer, second in the pre-IBM era, continued to be second in importance. There was a break in compatibility, as the IBM PC would not immediately work with complementary hardware or software from the previous standard.

Breaks in compatibility are rare and difficult in commercial computing.[36] They involve moving a body of customers and complementors away from the familiar standard to a new one. IBM had a very powerful brand name and reputation, and this was part of the way the firm found sufficient disruptive force to move the market. There was also a technical opportunity, as PC computing moved discontinuously from an 8-bit to a 16-bit foundation, and an associated market opportunity, as the expansion of the market to a new body of demanders who wanted somewhat different features in a computer (e.g., ease of use was more important for business people.) To compete with the many other initiatives to make a new 16-bit PC platform, some compatible with CP/M, IBM chose to change its view of what a computer company should be. Rather than being vertically integrated, as it had been in mainframes, IBM chose to have other firms supply key platform components—notably, to have Intel supply the microprocessor and Microsoft the operating system.[37] This offered IBM the opportunity to enter quickly (the specialized structure offering superior speed) and therefore take advantage of a contested market opportunity.

Thus, although the creation of the IBM PC involves continuity in the sense that a dominant firm from an earlier era of the industry was the leader, it involves fundamental change in other senses. First, IBM was not the original innovator of the PC segment; that called for entrepreneurship from outside the existing computer industry. IBM returned later to participate in technical improvements and commercialization and adapted itself to the structures of the new segment. Second, the continuity was not supported by policy but selected by markets. At the national level, the standard setting role for the PC segment would likely have stayed in the United States even without IBM's participation, as many of the other firms putting forward new PC architectures were American. Third, the move involved very considerable adaptation of existing capabilities, notably a dramatic shift in structure by IBM.

2.2.5.3 Shift of Control to Wintel While divided technical leadership permitted IBM to enter quickly and then dominate the PC segment, it left IBM with close complementors well positioned to wrest control of the PC segment's standards. The story of how first Intel encouraged direct entry against IBM, turning "clones" into "industry standard PCs," and then Microsoft gained control of the direction of the platform, is now well known.[38] For our purposes, the important lessons are threefold.

First, the value of having multiple distinct views of the future of the PC among which consumers could choose—in this case, at a minimum, IBM's, Intel's, and Microsoft's views—shows the value of strong market selection in ensuring ongoing growth of producer and consumer rents. The background to that selection was the wide range of experimentation and exploration in the United States and IBM's adaptation of the divided technical leadership model together with its own marketing capabilities.

Second, IBM lost control of the PC platform not to a new and superior form of PC but to a compatible one, with control shifting to complementors and previous partners. The divided technical leadership permitted this form of competitive improvement and enhancement to the platform, with the resulting considerable improvement in products and prices to the benefit of users, without the need for as radical and difficult a step as the earlier replacement of CP/M with the IBM PC. Indeed, not long after the shift of control of the platform to Intel and Microsoft, applications vendors Lotus and WordPerfect would undertake platform-steering efforts of their own, threatening the newly established platform leadership positions. Those efforts ended badly for Lotus and WordPerfect, as they themselves were victims of competition that originated from a seller of complements, Microsoft. Divided technical leadership declined as one firm controlled many key software layers in the platform.

Third, this was all without meaningful government direction, although the institutional and policy stance of the United States permitted the change. U.S. institutions throughout were supportive of new firm foundation and of market selection. Absent strong competition policies, IBM would have been easily able to take advantage of its position to block competition and to maintain control of standard setting in the PC.

2.2.5.4 Lessons of the PC Shifts The persistence of the U.S. national leadership through the series of changes in leadership associated with the PC business turns on a remarkable variety within that country in firm and regional capabilities. The elements of maintaining national leadership arise, not because of continuity, but because, at times of change, many of the interesting experiments with regard to new leadership were American. Thus, even though existing firm rents and/or existing technology rents were abandoned, this rigorous domestic competition continued to leave the rents of the industry in one country. This series of switches, from entrepreneurial start-ups (CP/M and Apple) to national champion (IBM) to adolescent technology specialists (Microsoft and Intel), illustrates the wisdom of a national policy that is completely neutral toward the form of successful supply. The critical features of national policy here were supporting experimentation and exploration over a wide range, which created a strong incentive for existing dominant firm adaptation, and supporting an environment in which market selection of the future winners cannot be blocked by the past ones. Finally, the division of technical leadership among multiple complementary producers of key components, possible in the United States because of the wide number of experiments with distinct firm capabilities and specializations, served the segment well in providing competition and the considerable speed advantages of divided technical leadership. Availability of many different firms to participate in distinct leadership roles drew not on any particularly successful efforts at national coordination (market forces were sufficient for coordination when needed) but on a national policy of broad support for invention, experimentation, and entrepreneurship. The fruits of those experiments, many of which had gone through long periods of earning small rents, were later adapted to the changing circumstances of the computer business.

2.2.6 Entry, after a Long Delay, into IBM's Mainframe Markets

IBM's dominance of the mainframe segment never ended. Mainframe customers, however, began in the late 1980s to have real competitive alternatives to IBM.

Entry that ultimately threatened IBM took a long time to develop. As discussed earlier, entry and competition from similar mainframe firms was not at all effective. An important limit on the scope of IBM's market was set by the invention of the superminicomputer, a machine based on minicomputer technology but running software suitable for commercial (not only technical) uses. In the late 1970s and early 1980s, formerly technical minicomputer firms, notably DEC, were able to adapt to a more commercial customer base. More broadly, a new vertically disintegrated supply was able to grow up, with entrepreneurial firms such as Oracle selling software for commercial computing but running on smaller and cheaper machines than mainframes. This new vertically disintegrated supply was, once again, overwhelmingly American, drawn both from start-up firms taking advantage of the entry opportunities afforded by vertical disintegration and existing firms adapting to the new market conditions. Notably, the successful adaptors did not include IBM, the closest established firm.[39] These events led to a limiting of IBM's market scope but by no means the end of IBM dominance, as the firm continued through the 1980s to be one of the world's most profitable enterprises.

It was at the end of the 1980s when a real challenge to IBM's position occurred. The immediate cause of this was not the invention of a better mainframe computer than an IBM one. Instead, networking technologies advanced to the point where users in large commercial sites could consider using a network of smaller computers instead of a single, large mainframe. The idea was that technologies previously used for technical computing—minicomputers and workstations—would provide the power previously available from mainframe systems. Users would access the networked system through the now familiar PC. Instead of mainframe and terminal, systems used "server" and "client" computers. While a variant of this particular technical idea had been under development inside IBM for some years, and indeed had been a major motivation for IBM's advancement of the PC platform, superior technical and market versions arose outside IBM. Particularly because these new firms had no strong reason to preserve IBM rents, they had incentives to take up technical and market solutions that replaced rather than enhanced IBM's position at many sites. Users did not migrate instantly, because of the considerable switching costs associated with longstanding lock-in, but what had been a strong market position for IBM was considerably weakened, because they had to compete with close and effective competitors for what had long been their most solidly committed sites.

This episode contains an important cautionary tale about national champions. Over the course of the 1980s, IBM anticipated the value of client-server computing in considerable detail, and sought to put itself in position to offer a complete solution to commercial sites running from client through middleware to server. As the dominant firm selling large, complex, networked applications, and as the dominant PC firm, IBM could offer a compelling story that it was well posed to be the supplier of the new platform. Use of market selection, rather than of efforts to preserve and maintain the existing producer rents, was the key to opening up substantial value for consumers of computers. As buyers made those choices and moved away from traditional computer vendors to new ones, the fraction of total investment represented by information technology capital (now including a great deal of data networking) grew dramatically, as did the contribution of IT applications to world economic growth.

The new firms were, once again, largely American. The national institutions supporting this competitive replacement and enhancement were, once again, not directive. In this era as well as in others, it was simple to start a new U.S. company to take advantage of this new opportunity. U.S. policy was not focused on preserving the existing IBM rents. If anything, policy supported the entrants' initiatives. It was at this juncture that some of the advantages of the almost forgotten IBM antitrust suit finally came to have a real payoff, as firms for long in the business of complementing IBM became participants in the platforms and important competitors once the "competitive crash" occurred. More generally, the entrants were a mixture of firms, some long-standing complementors to IBM adapting capabilities to participate in the new platform, some from outside the mainframe segment, similarly adapting capabilities, and others start-ups. The important point here about adaptation is that established firms other than the existing dominant firm are potential adaptors of capabilities to a new use.

2.2.7 Convergence of the Internet with the PC

By the mid 1990s, the PC sector had a single, strong dominant firm steering its platform, Microsoft. The main structural force that had permitted competition in this segment despite powerful network effects—divided technical leadership—had declined steadily over time. In the mid-1990s, developments on the Internet brought a new threat to Microsoft's position. Convergence of the Internet with the PC led to an opportunity to reestablish divided technical leadership. The addition of a browser layer to the PC industry was the key marketing force at work here, for the browser was a surprisingly popular new application.[40] The nature of the underlying competitive opportunity represented by the browser was a platform shift away from the PC, or at least the centrality of the PC, for individual productivity applications. Those might come to be more network oriented, adding Web browsing, e-mail, electronic purchasing, instant messaging, and so on to the familiar applications running on a single PC. This was another time at which there was discontinuous technical change and an associated market change opportunity.

While such a transition offered consumers the potential benefits of choice between existing technologies and vendors and new ones, such choice was not in the interest of the incumbent dominant firm. Microsoft saw the changes on the Internet, especially the wide distribution and use of a browser outside its own control, as a potential threat to its position and its market power. In deciding to make responding to the threat from the Internet a priority, Bill Gates, Microsoft's CEO, drew the analogy between the wide acceptance of the Netscape browser and the arrival of the IBM PC a generation earlier (Gates 1995). Each was, in his view, a significant enough event that it could be the opportunity to shift control of rents from one firm to another, or an opportunity to lower the rents earned by all firms as an era of stable positions ended, replaced by a period of rapid and disruptive change. Rather than finding itself in a position of uncontested platform leadership and operating system monopoly, Microsoft could find itself facing effective competition in the operating system business and potential replacement of that platform by a newer, technically superior one.[41]

Based on its PC experience, Microsoft decided that divided technical leadership would render its position more competitive. It thought that external control of such Internet-centric technologies as the browser and Java would lower barriers to entry into PC operating systems and would threaten its dominant position. It therefore acted to prevent widespread distribution of those innovative technologies under the control of other firms. Caught off guard by the sudden success of the Internet, and far behind in standards-setting races, Microsoft found itself unable to win by advancing its own versions of browser and Java technologies and giving them away for free, despite its considerable "strong second" skills in incremental technical progress and technology marketing. Having failed at competition, Microsoft turned to an impressively wide-ranging arsenal of anticompetitive tactics, exploiting clout of its existing monopoly position.[42] But for these anticompetitive acts, divided technical leadership would have reemerged in the PC business. More likely, we would now think of the part of computing serving individual end users as drawing on both the PC and the Internet; that segment would now have divided technical leadership.

The U.S. government challenged Microsoft's behavior in an antitrust case, arguing that demanders should get to choose among continuation of the status quo, increased competition going forward, or even a replacement of the existing platform with a new one. For our purposes here, the important question is not the exact nature of Microsoft's violations of the law but the purposes of the intervention. The government saw that the shift of personal computing from a stand-alone PC basis to a networked applications basis offered entrants an opportunity to present consumers with new choices about their mode of computing. Rather than necessarily staying with Windows, or a more networked descendant of Windows, consumers might have chosen a distinct operating system or even something "far cheaper than a Windows PC" (Gates 1995). Denying them that choice meant denying the industry the opportunity to move forward to a new supply model if that were what the market was to have selected.

The antitrust suit is at an intermediate stage. The courts, including an appeals court, have upheld the main charges against Microsoft.[43] An effective remedy, a divestiture to reestablish divided technical leadership and lower entry barriers into Microsoft's monopoly markets, was overturned by the appeals court on procedural grounds. The question of ultimate remedy has been left, at this stage, to a new court. The market, too, is at an intermediate stage. A challenge to Microsoft's leadership arose in the late 1990s, was cast aside by anticompetitive means, and still has not been presented to users of computers for their choice of continuity, partial continuity, or change.

The U.S. policy stance stayed consistent with that of the previous several decades in this lawsuit. In particular, the government appeared as the agent of choice between the new and the old. By acting in favor of a strong market selection mechanism, the government would, in this instance as in the past, enable change when the market preferred it but not force either change or stasis on the market.

2.2.7.1 The Founding of the Internet Sector

Is the founding of the Internet one of those examples of the use of defense procurement as an instrument of strategic trade policy? Many observers point to the common location of most Internet-related vendors in the United States in the late 1990s and the original location of the Internet as a U.S. defense-department sponsored network (then called ARPAnet) as an example of government investment that ultimately led to significant national advantage.

In fact, the Internet grew up as a technical computing network, largely linking minicomputers used by scientists and engineers in government and universities and, to some degree, similar people in firms. In that role, it came to be highly internationalized.

The important steps toward giving the Internet its modern role did not originate in the United States. The World Wide Web was promulgated by a Brit living in Switzerland. He drew on his own inventive powers and on technologies and connections that were global. The creation of the Web was only the beginning of a new commercial end-user-oriented computing network. The next critical step, the browser, was seen by entrepreneurs in American universities. They were reimporting a technology that had by then only limited U.S. elements.

The crucial elements of U.S. policy in creating a commercial Internet sector were supportive and enabling, not directive or "strategic," with regard to the Internet.

2.3 Lessons for Positive Economics

We have touched on what we think are the broad positive and policy issues as we have examined each of these periods, whether foundings or transitions, of determination of the international allocation of producer rents and of the computer industry's capacity to serve worldwide economic growth. We pull together these lessons here.

2.3.1 Rejection of the Broad Theory of U.S. Persistence

There is an oversimplified, broad theory that at first seems to explain U.S. persistence. It has three elements. (1) The United States, an early mover, has the largest domestic market, and the Department of Defense was a very important (price insensitive and nationalistic) demander in the industry's formative years. (2) Given first-mover advantages, the commercial winners were those with the greatest initial advantage. Thus, (3), the experience of the United States in computing illustrates the value of wise strategic trade theory. We hope that, by this juncture, it is obvious why we think that this oversimplified, broad theory is highly inaccurate.

First, let us be clear that part of this theory is right. Over shorter time scales within segments, the tendency has been for computing first-mover advantages to preserve firms' and nations' positions. One problem with this theory arises when it attempts to explain the longer time scale. Another arises with the positive political economy argument that the broad theory explains actual U.S. policy formation.

For the longer time scale the broad theory is very unsatisfying. The foundings of new segments described in the previous section are important discontinuities. Each new segment used a new technology to address a new demand and new types of users, typically with a new commercialization mechanism. Each new segment created specific types of user-producer relationships, and firms had different capabilities, organization, and strategies. The later periods of transition in the mainframe and PC segments were ones in which old segments came to be served by new firms, technologies, and organizational models, ones that involve change, not continuity, in the source of rents.

To understand the persistence of U.S. dominance, we need to understand these periods of radical change, founding of new segments, and major transitions in segment leadership. To understand the role of policy, we need to understand not simple stories of attempting to steer known rents to the United States, but a complex story of supporting private enterprise to get read to reap unknown rents or to meet current national needs having nothing to do with the commercial or trade interests of the United States. Most important, policy was firmly focused on enabling the rents of the future, not on protecting the rents of the past to the point of active hostility to national champions.

2.3.2 Concentration and Persistence: The "New Trade Theory" by Way of Modern Industrial Organization

We found that, for intermediate-scale time periods and within particular segments, the concentration and persistence of the producer rents in one country were largely as explained in the simple theory. Social increasing returns to scale occur in the higher-value computing segments and are associated with cumulative investments by sellers and considerable irreversibilities (sunk costs) by buyers. Those are powerful reasons explaining large producer rents, concentrated structure, and persistence at a national level.

These same forces are also powerful explanations for the success of the industry in enabling the creation of worldwide consumer rents. Social increasing returns to scale obtained in the mainframe segment, and in the improved networked segment that has been replacing it, have led to tremendous contributions to world productive capabilities. Social increasing returns to scale around a series of PC standards have also led to higher and higher levels of contribution to consumer surplus, though the blocking of market selection of a new structure in the late 1990s has slowed that process. Over the appropriate time scale, and with the appropriate limits on scope, the welfare as well as positive implications of social increasing returns to scale theory play out.

Thus, with the limitations that the results apply only on short time scales and within segments, our analysis confirms the importance of the forces that have led to an embrace of the broad theory of U.S. persistence and success. We differ with the broad theory, however, because we do not stop there. We go on to examine the longer time scale and the analysis across segments. This wider scale—the one that is appropriate to understanding the phenomenon of long-term U.S. success and to analyzing the industry's contribution to growth—contains many elements that contradict the overbroad theory. We have emphasized three outcomes that lead us toward a more complete story:

- The scope and nature of increasing returns and sunk costs changed several times as the technological basis of the industry changed.
- Market structure and the type of firm changed.
- User relations and the definition of effective commercialization changed.

These differences, and the way that they played out in the periods of rapid change and disruption that have characterized the industry over a longer time scale, lead us to a positive analysis that has three more elements in it.

2.3.3 Growth and Change

To understand the growth and change of the computer industry as a successful creator of opportunities for economic growth, and to understand its persistence in the United States over a longer time scale, we need to understand two kinds of periods of disruptive change and discontinuity.[44]

The first of these is *foundings*. For the computer industry, we have identified three major periods of founding: those of the industry overall (corresponding to the mainframe segment), the minicomputer segment, and the PC segment.

The second kind of periods is *transitions*. We have identified several periods of transitions, or potential transition, including the breakdown of barriers to entry into IBM mainframes, the transition from CP/M to the IBM PC, and the potential creation of an Internet-based replacement or major enhancement to the PC.

Looking at these periods of radical growth and change leads us to emphasize the unpredictability, ex ante, of the specific technical, marketing, or organizational structures that will come to be clear leaders in the industry ex post. Accordingly, each founding saw the creation of a supply side that met user needs only after a wide variety of explorations and experiments came forward with the winning one selected by a market process. The forces leading to success in a particular country ex ante are then related to the number and variety of experiments based on technical and market capabilities.

For transitions, adaptation led to a further source of exploration and experimentation. Existing firms can adapt existing technologies or marketing capabilities to the new needs of a segment after discontinuous change. Our examination of adaptation by the existing dominant firm in a segment has revealed that adaptation is by no means always successful, often made difficult by the fundamental changes in technology, structure/strategy, or commercialization/marketing capabilities that characterize periods of dramatic change.

Successful adaptation by outsiders to the segment from within the same country is a source of continuity at the national level even where there is change at the firm level. This is a point about adaptation that the literature has not always considered, focusing instead on the existing dominant firm. The computer industry has several important sources of outsiders ready to offer new experiments in times of radical change. The first comes from outside the segment but within the industry. We saw examples of entrants of this sort based on technical capabilities (minicomputers become superminicomputers or servers) or marketing capabilities (IBM enters the PC). Clearly, existence of firm capabilities or technologies in a nearby segment lowers the costs of certain experiments. Second, complementors to an existing dominant firm can be experimenters who become the dominant firm in the next era of the segment. We saw this in the importance of divided technical leadership in the PC segment, in the competitive crash, and in the PC/Internet convergence. Either kind of adaptation, the next-segment kind or the complementor kind, may be undertaken by existing firms or by entrepreneurial entrants that take the opportunity to adapt.

In sum, the importance of all these points is to belie a common view: increasing returns-to-scale industries need, at a national level, technology and market investments that are coordinated to a single goal. Within the intermediate time period and within the segment, powerful market forces will tend to achieve that coordination. At the longer time scale, however, it is the breadth and variety of experiments and capabilities followed by market selection, not any coordination on a single goal, that explains the persistence at a national level. This occurs because of the powerful force of uncertainty, a force that comes to the foreground in times of discontinuous change.

2.4 Lessons for Policy

These views of the positive economics of (1) international success in the computer industry and (2) success in meeting a changing set of user needs over time lead us to a specific view of the public policy issues.

Just as there was a false, overbroad positive theory of U.S. success, there is a false simplicity about certain policy prescriptions. The existence of scale economies, such as the social increasing returns to scale so important in many computer segments, does not imply the wisdom of a policy that protects national champions. Nor does it imply the wisdom of any other policy of picking winners, even ones that sometimes seem wise, like assigning to governments the duty of coordinating disparate national efforts around certain common goals or standards. A worldwide strong market selection mechanism means that individual governments cannot have a local protectionist mechanism. Instead, rigorous domestic competition is the key to selection in world markets.[45]

However, this does not mean that the proper role of government policy or other national institutions is completely passive. It simply means that it has to be enabling rather than directive. National institutions and policies that encourage experimentation and exploration in a wide range of technologies have been effective by not pushing the industry toward any particular strategic trade policy goal. Instead, they permit entrepreneurship by new companies and adaptation by existing ones hoping to be major players in the new field. Finally, national institutions can ensure that strong market selection mechanisms bring demanders as well as suppliers to bear on the choice of organizational structure, technology, and mode of commercialization. Such policies may be unsatisfactory to governments eager to be able to claim credit for causing industrial growth and development. But they arise from the fundamental limits of what policy can knowingly direct, and what it should leave to markets, in circumstances of uncertainty.

While not always perfect, U.S. and to some extent Japanese and Taiwanese national policies and institutions have respected these market realities. That long-standing respect for the marketplace continues into the present in the formation of U.S. policy.

Notes

The authors, who are at Stanford University, United States, and CESPRI, Bocconi University, Italy, thank SIEPR and the Italian CNR for support.

1. We use "rent" here in the economic sense of meaning a high return to an asset, factor of production, or capability. Engineers who might work in the computer industry earn far more in the United States: that is a rent to U.S. human capital. Similar rents have been earned by U.S. firms.

2. One of the authors, Bresnahan, worked on the Microsoft antitrust case while at the Department of Justice.

3. The boundaries of the mainframe segment are not clear. Commercial minicomputers eventually became much like mainframes, for example. We treat the boundary competition between mainframes and other kinds of computers as unimportant for the period 1955–1989. The much more powerful competitive forces unleashed against mainframes in the "competitive crash" of the 1990s we treat elsewhere in the chapter.

4. On this, see Bresnahan and Greenstein 1999.

5. This is of course a key point in the strategic analysis of dominant firms in technology-intensive industries, the ability of the incumbent

firm to see through the "Arrow effect" and innovate to maintain its position.

6. There are some exceptions, notably the successful production of plug-compatible computers and other components by competitor firms, notably Japanese ones. Yet control of the compatibility standard associated with modularity (the key to producer rents) stayed with IBM.

7. See Krugman 1992 and Helpman 1998.

8. The theory of social scale economies and collectively sunk costs has been carefully worked out by, for example, Farrell and Saloner 1985 and Katz and Shapiro 1986.

9. See Bresnahan and Greenstein (1999), particularly on why *compatibility forces* meant that the scale economies continued to matter even as the market grew. If this had not been true, the segment would likely have had a monopolistic competition structure with many successful selling firms, each with products suitable to a class of customers. This monopolistic competition structure is more emphasized in the NITT literature, but what really matters for application is not the special case assumed in the theory but that the strategic opportunities available to firms are one important input into the international industry structure and the allocation of rents.

10. The case did, however, lead IBM to unbundle mainframe computer hardware from software such as the operating system in an attempt to head off prosecution. This led to modest increases in competition in the short run and contributed to substantial increases down the road.

11. See also Bresnahan and Malerba 1998. Briefly, European countries erected barriers to exit for single national champion firms. Japanese policy restricted attention to a modest number of existing, successful electronics firms with government support, but insisted on competition among them and on success in exporting as conditions for ongoing support. Ultimately, the Japanese achieved a near miss, with a plausible effort to leapfrog IBM.

12. For analysis of strategic trade policy, see Dixit and Kyle 1985 and Krugman 1993.

13. In Japan, experimentation at this early stage was limited, since there was not much advanced technical capability. See Bresnahan and Malerba 1998 for a detailed discussion of the European and Japanese cases.

14. European companies, possibly anticipating protected domestic markets, followed two strategies. If they were electronics firms, they tended to produce computers optimized for scientific calculation. If they were business equipment firms, they tended to make small in vestments in electronic technology. There is an interesting counterfactual question of whether a united European market would have led to these same supply choices. Given that most U.S. firms (other than IBM) similarly followed their original trajectories, there is reason to doubt it, however.

15. See Rosenberg 1996 on the role of uncertainty of this type in high technologies generally and Bresnahan and Malerba 1998 for a far more detailed treatment of the issues covered here.

16. This adaptation involved considerable innovation within the company, including elements of separating the new from the old. See Usselman 1993. Other business data processing companies, including European ones, were far less successful at shifting to electronic computing.

17. See Metcalfe and Gibbons 1987 and Nelson 1995; see also Cohen and Malerba 1995 for the similar case of complementary learning.

18. See Evenson and Kislev 1976 and Nelson 1982.

19. See Cohen and Klepper 1992.

20. Indeed, IBM was quite hostile to the role of the government, delaying until late any research collaboration with government agencies or government-sponsored research. See the chapter titled "Government-Sponsored Competition" in Pugh 1995.

21. The United States relied on market mechanisms for selection, a goal supported to the small extent necessary by policy. Automatic continuity of tab-card-era dominant firm IBM as the commercial data processing dominant firm was opposed by the government in a (moderately effectual) antitrust suit.

22. For example, the purpose of government-sponsored ENIAC was to be able to numerically integrate so that, for example, artillery shells might land on the enemy's tank. This was exactly the technical direction *not* taken by IBM.

23. See Klepper 1996 and Metcalfe 1997.

24. As we will see, minicomputer technologies were later used to serve other bodies of demand.

25. For example, there is a mixture of proprietary operating systems (such as those on the DEC Vax family) and open but not completely identical ones (such as UNIX).

26. See Henderson 1993 and Henderson and Clark 1990 for analytical treatments.

27. After a series of failed entry attempts, IBM had a successful minicomputer line only in the late 1980s, and that was after the invention of the "commercial minicomputer," namely, minicomputer technology used by demanders more like mainframe users.

28. For analytical sources, see nn. 17–19.

29. Further analysis in work cited at n. 23.

30. IBM chose a nonintegrated structure for the IBM PC in order to obtain this speed.

31. See Bresnahan and Malerba 1998 for more detailed analyses of the American, European, and Japanese cases.

32. Aw, Chen, and Roberts 2001 and Saxenian 2000. These papers argue that the pro-market-selection policies of Taiwan have moved it into a hardware rent-generating position in the industry just as the rents in the United States have gone to software.

33. See Grossman and Helpman 1991a, b for relevant theory.

34. The important exception is IBM, to which we shall turn in a moment. A number of existing firms attempted the adaptation, only to fail, including such impressive (on their own ground) vendors as DEC and AT&T.

35. Famously, IBM sent the PC organization to a separate geographical location (Boca Raton, Florida) in order to prevent influence on it from elsewhere in the company.

36. See Bresnahan and Greenstein 1999 for more analysis and more detail on this break.

37. Though they were not recruited at the beginning to play a platform-component role in the PC, such widely distributed applications software vendors as Lotus (spreadsheets) and WordPerfect (word processors) came to have a role in the technical leadership of the PC platform.

38. See Ferguson and Morris 1993 and Bresnahan and Greenstein 1999.

39. See Bresnahan and Greenstein (1999) for an analysis of the dilemma facing IBM.

40. See Gates 1995 for the observation that the key change was the widespread and popular use of the Internet—driven by the Netscape browser.

41. See Gates 1995 for discussion. Numerous other Microsoft planning documents show this reaction as well, but this one has the CEO arguing in detail for a radical change in the strategic direction of the company.

42. A number of sources describe these anticompetitive acts in detail. See Bresnahan 2001, Jackson 1999, and CADC 2001 for three approaches.

43. See CADC 2001. The main charge, that of maintaining the Windows monopoly, was upheld. Several of the specific acts found illegal might also have been illegal for a second reason, and the appeals court failed to find them illegal for two reasons.

44. A small literature is beginning to take up the analysis of industries that undergo change and renewal, and for which our intermediate-run vs. long-run distinction is material. See Jovanovich and MacDonald 1994 and Klepper-Simons 2000.

45. This argument closely follows that of Porter 1998.

References

Aw, B. Y., X. Chen, and M. J. Roberts. 2001. "Firm-level evidence on productivity differentials and turnover in Taiwanese manufacturing," *Journal of Development Economics* 66: 51–86.

Bresnahan, T. 2001. "The economics of the Microsoft case." Mimeo., Stanford University, available on-line at ⟨http://www.stanford.edu/~tbres⟩.

Bresnahan, T., and S. Greenstein. 1999. "Technological competition and the structure of the computer industry." *Journal of Industrial Economics* 47(1): 1–40.

Bresnahan, T., and F. Malerba. 1998. "Industrial dynamics and the evolution of firms' and nations' competitive capabilities in the world computer industry." In *The Sources of Industrial Leadership*, ed. D. Mowery and R. Nelson. Cambridge: Cambridge University Press.

CADC. 2001. *Order, affirming in part, reversing in part, and remanding in part, in* US vs. Microsoft, 00-5212.

Cohen, W., and S. Klepper. 1992. "The anatomy of industry R-D intensity distributions." *American Economic Review* 82: 773–788.

Cohen, W. M., and F. Malerba. 1995. "Diversity, innovative activities and technological change." Mimeo., Carnegie Mellon University and Bocconi University.

Dixit, A., and A. Kyle. 1985. "The use of protection and subsidies for entry promotion and deterrence." *The American Economic Review* 75: 139–152.

Evenson, R., and Y. Kislev. 1976. "A stochastic model of applied research." *Journal of Political Economy* 84: 256–281.

Farrell, J., and G. Saloner. 1985. "Standardization, compatibility, and innovation." *The Rand Journal of Economics* 16: 70–84.

Ferguson, C. H., and C. R. Morris. 1993. *Computer Wars: How the West Can Win in a Post-IBM World*. New York: Times Books/Random House.

Gates, B. 1995. "The Internet tidal wave." Microsoft Internal Memorandum, May. Available as GX 20 in *U.S. v. Microsoft*.

Grossman, G., and E. Helpman. 1991a. "Endogenous product cycles." *The Economic Journal* 101: 1216–1230.

Grossman, G., and E. Helpman. 1991b. *Innovation and Growth in the Global Economy*. Cambridge, MA: The MIT Press.

Helpman, E. 1998. "The structure of foreign trade." Mimeo., Harvard University, August. Based on the Bernard-Harms Prize Lecture.

Helpman, E., and P. R. Krugman. 1989. *Trade Policy and Market Structure*. Cambridge, MA: The MIT Press.

Henderson, R. 1993. "Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic industry." *RAND Journal of Economics* 24(2): 248–270.

Henderson, R. M., and Kim B. Clark. 1990. "Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms." *Administrative Science Quarterly* 35: 9–30.

Jackson, T. P. 1999. *Findings of Fact*, U.S. District Court for the District of Columbia, *U.S. v. Microsoft*, Civil Action No. 98B1232 (TPJ).

Jovanovich, B., and G. MacDonald. 1994. "The life cycle of a competitive industry." *Journal of Political Economy* 102: 322–347.

Katz, M., and C. Shapiro. 1986. "Technology adoption in the presence of network externalities." *The Journal of Political Economy* 94: 822–842.

Klepper, S. 1996. "Entry, exit, growth and innovation over the product life cycle." *American Economic Review* 86: 562–583.

Klepper, S., and K. Simons. 2000. "The making of an oligopoly: Firm survival and technological change in the evolution of the U.S. tire industry." *Journal of Political Economy* 108: 728–760.

Krugman, P. R. 1992. "Technology and international competition: A historical perspective." In *Linking Trade and Technology Policies*, ed. H. M. Caldwell and G. E. Moore. Washington DC: National Academic Press.

Krugman, P. R. 1993. "The Current Case for Industrial Policy." In *Protectionism and World Welfare*, ed. D. Salvatore. Cambridge: Cambridge University Press.

Metcalfe, S. 1997. *Evolutionary economics and creative destruction*. London: Routledge.

Metcalfe, J. S., and M. Gibbons. 1987. "Technological variety and the process of competition." *Economie Appliquee* 39: 493–520.

Nelson, R. 1982. "The role of knowledge in R-D efficiency." *Quarterly Journal of Economics* 97: 453–470.

Nelson, R. R. 1995 "Recent evolutionary theorizing about economic change." *Journal of Economic Literature* 33: 48–90.

Porter, M. 1998. *Competitive Advantage*. New York: Simon and Schuster.

Pugh, E. W. 1995. "Building IBM: Shaping an industry and its technology." Cambridge, MA: The MIT Press.

Rosenberg, N. 1996. "Uncertainty and Technological Change." In *The Mosaic of Economic Growth*, ed. R. Landau, T. Taylor, and G. Wright. Stanford: Stanford University Press.

Saxenian, A. 2000. "Taiwan's Hsinchu region: Imitator and partner for Silicon Valley." Stanford SIEPR Discussion Paper #00-044.

Usselman, S. 1993. "IBM and Its Imitators: Organizational Capabilities and the Emergence of the International Computer Industry." *Business and Economic History* 22(2) (Winter): 1–35.

This page intentionally left blank