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Explaining the Resurgence of U.S. Competitiveness: The Rise of Wintelism

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What explains the resurgence of U.S. international competitiveness in the 1990s? The previous decade can be characterized as one of intense U.S. concern about its declining international competitiveness. In this article, we argue that U.S. industry adopted a new industrial paradigm called "Wintelism" in response to competitive pressures from western Europe and East Asia. The essence of Wintelism is a reliance on open but owned technical standards and extensive outsourcing of component production to enable industrial structures to become less vertically and more horizontally integrated. Countries like the United States that pursued a modified regulatory state approach to structuring state–societal relationships found it easier to adopt this new paradigm than countries that pursued the developmental state approach.

Keywords wintelism, computer industry, technology, institutions, government policy

The current debate over the causes of the resurgence of U.S. international competitiveness in computers and other information industries is in sharp contrast to the debates of the 1980s and early 1990s over the relative decline of U.S. international competitiveness in other important industries: most notably, steel, autos, consumer electronics, and parts of the semiconductor industry. The main question posed here is how to explain this resurgence in a systematic way.

We attempt to explain U.S. success in the computer and electronics industry by stressing the creation and maintenance of supportive governance structures appropriate to the growth of those industries. Building on Borrus's and Zysman's work (1997), we attempt to explain the appropriateness of supportive governance structures by applying the concept of *Wintelism*. Borrus and Zysman note that *Wintel* is a "code word . . . created by linking the names of the two most evident major victors of the new standards competition: Microsoft Windows the software operating system and Intel microprocessors" (Borrus & Zysman, 1997, p. 141) Wintelism, they explain,

> is the code word . . . to reflect the shift in competition away from final assembly and vertical control of markets by final assemblers. Competition in the Wintelist era, by contrast, is a struggle over setting and evolving de facto product market standards, with market power lodged anywhere in the value chain, including product architectures, components, and software. (Borrus & Zysman, 1997, p. 162)

Building on their seminal work, we define Wintelism as the structural dominance of components providers, like Intel and Microsoft, over assemblers, like IBM and Dell, effected by applying strategies for controlling architectural standards in a horizontally segmented industry. We believe that Wintelism is not limited to the contemporary computer and electronics industries, but may be extending its influence to other manufacturing industries such as the automobile industry.[1]

The United States is currently the most successful country in the world in adjusting to the rise of Wintelism as a new industrial paradigm. Modifications in American institutions in response to increased competition from other

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industrialized countries—especially Japan—helped to assure the success of American computer companies, Microsoft and Intel, in particular, but other firms as well, and the resurgence of U.S. international competitiveness in general. In the process, a horizontally integrated industry structure emerged and the traditional regulatory role of the state was modified to deal with the specific needs of the industry. It is our view that this institutional adaptation to the rise of Wintelism explains the resurgence of U.S. international competitiveness.

FRAMEWORKS FOR ANALYZING THE RELATIONSHIP BETWEEN TECHNOLOGICAL SYSTEMS AND GOVERNANCE STRUCTURES

In this section we use a modified version of Herbert Kitschelt's framework (1991) on the match between technological properties and governance structures to explain the relationship between American industrial institutions and U.S. competitiveness in computer industry. Kitschelt's work draws on recent contributions to organizational theory in sociology, economics, and business history to distinguish analytic types of technological systems as industrial sectors. In particular, he relies on two main theoretical sources—Charles Perrow (1984) on technology and organization and Oliver Williamson (1985) on technological systems and governance structures. Kitschelt argues that any technology has two important dimensions that influence the choice of governance structures: one is the *degree of coupling* in the elements of a technological system, and the other is the *complexity of causal interactions* among production stages.

First, the *tightness of coupling* refers to the requirement for spatial or temporal links between different production steps. In tightly coupled systems, there are close spatial and temporal links between production steps. Thus, the production steps must be done at the same location or at the same time. In loosely coupled systems, however, each step or component of production is separated from every other step in space and time. Thus the production steps can be done in any sequence at any location. Tight coupling requires close supervision in order to contain problems that might otherwise spread quickly to other processes, but loose coupling permits less centralized control because errors in system components do not easily affect the entire system. In short, the more tightly technological elements are coupled, the more control needs to be centralized.[2]

This concept of coupling is closely related to the scale of the economy: the amount of capital investment required, the size of firms and individual production facilities, and so forth. If a technological system is tightly coupled, it generally requires a large economy with high levels of capital investment for local firms to be successful. However, if the technological system is loosely coupled, it does not require a large economy or large amounts of capital investment for firms to be successful. Kitschelt also relates the tightness of coupling to the organizational pattern of research and innovation (R&D): "Tightly coupled systems require 'global' learning in which innovation addresses the mutual fit of all system components. Loosely coupled systems, in contrast, can afford more 'local' learning through improvement of individual system components" (Kitschelt, 1991, p. 462).

Second, the *complexity of causal interaction* refers to the importance of the feedback among production stages that is required to keep the whole process on track. In systems with complex interaction, elements influence each other mutually and engage in circular causal interaction. These systems have large information requirements to manage the intricate flow of connections across processes. Systems with linear interaction proceed from one stage to the next without feedback, and the causality between elements is not complex. Thus, linear systems have lower information requirements. In complex interactive systems, the monitoring, analysis, and correction of production processes take place in decentralized organizational units, because a centralized control unit would be quickly overloaded. In contrast, less complex systems with linear causality among the components are more amenable to centralized control because the straightforward intelligibility of linear interactions reduces the probability that centralized control units will be overloaded with information.[3]

Causal complexity is closely related to problem-solving approaches in research and development. If a technological process is in complex causal interaction, then its trajectories involve greater uncertainty in the interplay of system components and are not readily predictable. Thus, technological innovations have to be explored by trial and error, and major breakthroughs are followed by small incremental improvements. However, if the technological process is a linear system, then its trajectories are predictable and production advances in continuous, incremental steps. These trajectories are associated with low levels of uncertainty and risk, thus facilitating programmed, incremental strategies of problem solving.

The concepts of tightness of coupling and complexity of causal interactions are very useful in distinguishing types of technological systems and in understanding how each system may be supported by different governance structures. Kitschelt hypothesizes that each system requires a distinct governance structure for maximum performance.[4] Although the specific combination of coupling and complexity of a technological system does not determine a uniquely optimal governance structure, it does at least constrain the efficient possibilities. In the next section, we analyze the properties of the technological system connected with computers and information technology in terms of Kitschelt's categories and discuss what types of governance structures match that system.

THE PC INDUSTRY AND ITS GOVERNANCE STRUCTURES

The rise of Wintelism is based on technological changes in the computer industry during the late 1970s and early 1980s. The pivotal event among all these changes was the shift in technological focus from mainframe computers to the new computing environment, in which almost every user had access to a personal computer (PC) with its own processing capabilities. Increasingly, the user's PC was connected to others via the Internet, but the new environment we discuss here continued to depend mostly on the stand-alone computing capabilities of PCs.

The technological shift to the PC era originated with the introduction of new technologies that reduced both the cost and size of computers. Integrated circuits, introduced in the late 1970s, were smaller, less expensive, and more reliable than the semiconductors that had been used in mainframe computers. The software components of PC systems gradually gained greater significance than they had in mainframe systems.[5]

We focus the rest of this section on the part of the computer industry that is software dependent: computer software itself, micro-code, semiconductor chip designs, and technical standards in products and services. We are not talking about the hardware aspects of computers: components or systems assemblies, such as memory chips, flat-panel displays, floppy disk drives, hard disk drives, and printers. We want to focus particularly on technologies associated with *computer architecture*, such as the published and unpublished standards and interface protocols that allow designers to make sure that hardware and software work together. As Morris and Ferguson hold,

> The standards [for architectural technologies] define how programs and commands will work and how data will move around the system—the communication protocols and formats that hardware components must adhere to, the rules for exchanging signals between applications software and the operating system, the processor's command structure, the allowable font descriptions for a printer, and so forth. (Morris & Ferguson, 1993, p. 88)

PC architecture is defined mainly by the microprocessor, basic input output system (BIOS), data bus, and operating system software. All elements are usually referred to together as a *platform*. For example, the IBM-compatible platform means use of the MS-DOS/Windows operating system and an Intel ×86 microprocessor (or clone thereof) in the context of compatible BIOS. Upon the platform, software developers write application software, and thus software written for one platform will not run on another without necessary modifications.[6] Architectural technologies are frequently perceived to be at the core of PC technologies generally.

PC technologies are distinguishable from other technological systems by certain important properties:

First, PCs are a *loosely coupled* technological system. Each step or component of production is separated from every other step in space and time. Thus the production can occur in almost any sequence at any location because loose coupling permits *decentralized* control. The modularity of PCs means that parts, subassemblies, components, and peripherals can be purchased wherever the best price/performance ratio can be obtained. The suppliers for PC assemblers compete with one another to supply components that work on a specific platform. These components are designed around standard interface protocols to ensure interoperability among the components. Published architectural standards, such as interface standards, permit the assemblers to pick the most advanced components at the lowest possible price to compete with other assemblers.

Second, the PC industry is a *complex interactive* technological system. PC design and development takes place in decentralized organizational units, because centralized control units would be quickly overloaded with too much information. For example, the whole process of developing new operating systems, including design, coding, testing, and integration, entails a tremendous amount of feedback and informal communication within the firm and with allied firms. The same is true for the development of new microprocessors. Thus, technological trajectories of the PC industry are not readily predictable in time, cost, or final results. The development of innovative computer software technology is usually the result of trial and error, also called *learning by doing* (Schware, 1989, pp. 40–66; Rosenberg, 1982).

Complex feedback must occur to coordinate problems between the firm and end users of software products. Neither developers nor end users can tell exactly what is a truly desirable element of a software system before actually using it. Occasionally, even the end users themselves do not know beforehand what they really want a new product to do. This is called *learning by using* (Rosenberg, 1982). Close interaction between producers and sophisticated users is critical in the software development process. According to Dedrick and Kraemer, "the alpha and beta testing of new software generations provides invaluable feedback to software developers on the features desired by users and helps eliminate bugs before the programs that help expand the market for a product" (Dedrick & Kraemer, 1998, p. 103).

The technological properties of the PC industry require a flexible institutional environment made possible by *decentralized* governance structures. The PC industry, unlike the mainframe industry, no longer rewards the organized capabilities of *vertically* integrated private or state-owned enterprises or the *interventionist* role of the state. Smaller startup firms with cross-regional or cross-national networks, often financed with venture capital, are emerging as the *fittest* industrial governance structure. Nevertheless, in those areas where R&D uncertainties are substantial and knowledge intensity is high or where the architectural standards are too uncertain for the development of the industry, there are still incentives for large, horizontally integrated firms (like Apple, Microsoft, and Intel) to define a platform for all the other firms in the industry to design their products around. Herbert Kitschelt, noting the mix of large and small firms in the PC industry, argues that although

> corresponding governance structures [in the PC industry] include mixed regulatory requirements and the exigencies of effective global marketing strategies give large corporations an advantage, unprecedented organizational decentralization nevertheless continues to prevail under the umbrella of the large corporation. (Kitschelt, 1991, p. 474)

Hence an industry governance structure in which large firms dominate certain crucial horizontal segments and where there are intercorporate alliances among those corporations and both their customers and suppliers is needed to provide the necessary financial and technological support for the growth of the industry. The appropriate state governance is one that promotes this kind of industrial governance structure. We argue next that a modified *regulatory* state—rather than an *interventionist* or *developmental* state—is best able to promote innovative startup firms, to impose antitrust laws on large firms, and consequently to encourage the value-chain specialization that defines the PC industry (and, by extension, all Wintelist industries).

STRUCTURAL TRANSFORMATION OF THE COMPUTER INDUSTRY

From the computer industry's earliest beginnings, it was dominated by a small number of very large companies, most of which were *vertically integrated assemblers*, such as IBM, Honeywell, Siemens, Matsushita, NEC, and Toshiba. These companies were responsible for all the key aspects of design, manufacturing, software, sales, service, and support in producing mainframe computers. IBM, the producer of the System/360 series and subsequent mainframe offerings, was the largest of them all. More than any other single product line, the System/360 family entrenched the vertically integrated industry structure depicted in Figure 1 (Grove, 1996; Moschella, 1997).

In the later 1970s and early 1980s, however, with the introduction of the PC, the giant computer system producers lost out to specialized companies that were better adapted to particular segments. The giant corporations lost out because they had too much organizational overhead and took too long to make decisions. For example, IBM, which stood like a colossus astride the industry ever since it came into being, began spilling red ink in 1991 and by 1992 had posted a loss of some $4.9 billion. The manufacture and sale of computer hardware proved to be no longer the highly profitable business it once was. Instead, the computer industry was increasingly dominated by smaller companies that were much more nimble than the once-dominant giants (Umeda, 1994, pp. 33–34).

This structural transformation of the computer industry was accompanied by the rise of competition over architectural standards. Standards competition changed what companies had to do to win in the market and, by so doing, changed the number and types of firms in the industry.[7] By the late 1980s, large mainframe companies were in deep trouble, and it became increasingly clear that the shift to a new computer culture was irreversible. The rise of competition over architectural standards was an essential part of the transition from the *vertically* integrated industry structure of the mainframe industry to the *horizontally* integrated structure of the PC industry.

The analytic framework of PC industry technology and governance structures outlined earlier can provide a systemic explanation of why the competition to establish

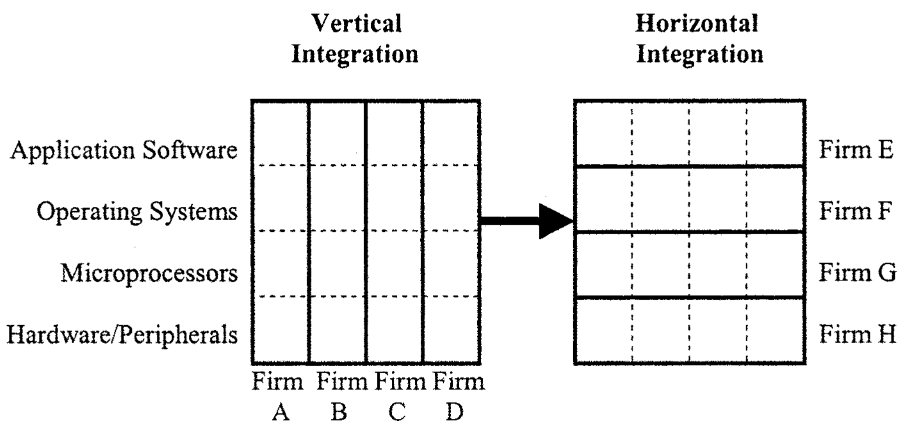

FIG. 1. The transformation of the computer industry. Modified from Grove (1996).

de facto standards forced firms and states to adopt horizontal governance structures in the industry. The technological properties of the PC industry—a loosely coupled technological system with high causal complexity—required *decentralized* governance structures coordinated through *horizontal* connections. The modular and open character of the PC meant that certain firms could produce and assemble parts, subassemblies, and peripherals anywhere in the horizontally segmented value chain, while others could potentially control the evolution of key standards and in that way define the terms of competition not just in their particular segment but, critically, in end-product markets as well (Borrus & Zysman, 1997, p. 150).

The existence of dominant standards plays a critical role in coordinating and integrating all the work of components suppliers. Each supplier firm adds value to the final system by producing needed components. Suppliers try to make their products conform to de facto market standards to maximize the potential market for their products. Suppliers compete with each other by adding incremental improvements in performance, functionality, features, quality, or costs within the dominant market standard. In short, competition in architectural standards not only encourages the value-chain specialization in the computer industry, but it also coordinates the segmented value-chain in a unified way. In this sense, the standard setting itself is a form of governance.

WINTELISM IN THE U.S. COMPUTER INDUSTRY

We next examine how Wintelist industrial governance fits the institutional requirements of architectural competition in more detail. There are four organizational and institutional aspects of Wintelism industrial governance: (1) specialized corporations with horizontal organizational structures, (2) horizontally segmented industrial structures, (3) horizontal industrial alliances, and (4) cross-national production networks at the global level.

First, the rise of Wintelism stimulated the development of horizontally organized *corporate organizations*. Specialization, flexibility, and speed were key factors affecting the success of companies in the PC industry. Small specialized companies could respond quickly and decisively to shifts in both technology and demand. Smaller companies tended to be more focused than larger ones. They were "not saddled with sunk costs from previous large investments, and thus they can change direction quickly to respond to new opportunities . . . . Such companies tend to be more aggressive in pursuit of new market opportunities and are more willing and able to bend the rules when necessary to get something done quickly" (Dedrick & Kraemer, 1998, p. 215).

Being small was not always an advantage, however. Many of the constraints associated with small-scale operations remained despite such new opportunities for smaller organizations. As Borrus and Zysman state,

> We are not entering an era of small and flexible firms. Rather, over time, significant imperatives of scale are emerging in different parts of the value chain, notably in production, product development, the dynamics of standardization, and distribution. (Borrus & Zysman, 1997, p. 159)

In fact, firms could be small when they entered the market, but they had to engage in increasingly large-scale investments to maintain a dominant position, once achieved, in fast growing markets. More importantly, firms needed to make large investments to deal with the complexity of problem solving in successive generations of PCs and PC components.

Intel's competitive advantage, for example, rested on its ability to build and operate increasingly expensive chip fabrication facilities to produce circuits with smaller and smaller line widths. To do this, it was necessary to mold and integrate the activities of increasingly large teams of engineers for designing and developing both new products and new production technologies. According to Alfred Chandler, "Intel's initial commercialization of the microprocessor was a team effort. The development of the 386 and the 486 required the funds, the knowledge, and the skills that were not available to entrepreneurial start-ups" (Chandler, 1997, p. 99).

Microsoft accumulated enormous financial and technological resources that enabled it to sustain a high level of R&D and/or to acquire any strategic technology that it could not produce in-house. Bill Gates made the following comment on the sources of Microsoft's strategic strength: "It is all about scale economics and market share. When you are shipping one million units of Windows software a month, you can afford to spend $300 million a year improving it and still sell it at a low price" (Chandler, 1997, pp. 99–100; Cusumano & Selby, 1995; Cusumano & Smith, 1997).

Corporate structure, corporate culture, and management style were often more important than firm size. Large firms were often saddled with overly bureaucratic decision-making structures and with too many layers of management, making it difficult for them to move quickly. Organizational structures useful for managing traditional, closed, integrated businesses usually did not work well for companies that competed in the PC industry.

However, large companies could be managed in a very decentralized or horizontal corporate structure. For instance, individual units of Hewlett-Packard (HP) operated almost as separate companies and were encouraged to maximize their own profits even if it meant competing with other HP units. This was one reason why HP, a large firm, successfully adjusted to the new era, while many other large firms did not. Specialized firms within horizontal segments—even if they were giants—might be able to compete successfully with smaller firms by specializing in that segment, defining market standards, and servicing the needs of the PC assemblers.

Standards competition encouraged horizontal and nonbureaucratic corporate structures. Architectural standards permitted many subsystems to be developed independently and still work together gracefully. They also permitted clean separation between centralized general-purpose functions and decentralized or specialized functions, and enabled management of unpredictability and change. The organizational structure of companies engaged in standards competitions was usually very flat, and development groups had simple, clean interfaces to each other determined by architectural boundaries. This horizontally integrated, nonbureaucratic entrepreneurial structure was an important feature of American software and integrated circuit manufacturing companies found in Silicon Valley.[8] Ferguson and Morris called this *the Silicon Valley model* (Ferguson & Morris, 1994, pp. 175–176).

Second, the rise of Wintelism brought about a horizontally segmented *industrial structure*. In the mainframe computer industry, the key components and software were produced in-house by the individual manufacturers. In contrast, the PC industry from its earliest beginnings adopted a horizontal supplier structure, consisting of competitive PC assembler firms and independently owned and operated suppliers. Companies such as Intel, AMD, Microsoft, Novell, Lotus, Adobe, Seagate, Oracle, 3Com, and others thrived by specializing in producing particular components or software for PC assemblers like Acer, Dell, Gateway, IBM, Toshiba, and Compaq.

In this horizontal industrial structure, a handful of companies supplying components to PC assemblers defined and controlled key technical specifications that came to be accepted as de facto product standards in the market for each layer of the PC system. Borrus and Zysman argue that

> Market power has shifted from the assemblers such as Compaq, Gateway, IBM, or Toshiba, to key producers of components (such as Intel); operating systems (such as Microsoft); applications (such as SAP, Adobe); interfaces (such as Netscape); languages (such as Sun with Java); and to pure product definition companies like Cisco Systems and 3COM. (Borrus & Zysman, 1997, p. 150)

The character of this shift in market power was popularly suggested in the recent advertisements of PC assemblers like IBM, Toshiba, Compaq, and Dell. They acknowledged that their nearly identical systems were equipped with the same microprocessors and operating systems that became de facto market standards by attaching stickers of *Intel Inside* and *Microsoft Windows Installed* rather than stressing the unique features of their own brands. They did this because they understood that consumers were more interested in interoperability than in uniqueness of systems.

Both Intel and Microsoft worked hard to establish a brand name identity for their component technologies. Although the microprocessor was responsible for most of the performance improvements in personal computers, it was buried in the cream-colored, opaque box that was the personal computer until 1991, when Intel went directly to end users, advertising heavily and promoting its *Intel Inside* logo in numerous technical and business magazines, and on national television. It also promoted its logo by offering PC assemblers discounts on chips if they displayed the *Intel Inside* logo on the PCs they sold.[9] Microsoft adopted a similar policy with its own logo *Microsoft Windows Installed* for makers of Windows-compatible software. In addition, Microsoft insisted that PCs sold with the Windows operating system display a common "splash screen" after the computer "booted up."

Third, the rise of Wintelism encouraged the formation of horizontal *industrial alliances*. Within the horizontally segmented industrial structure, firms usually formed strategic alliances across segments. Alliances sprang up in other parts of the industry between manufacturers and suppliers and between manufacturers and large retail chains. These alliances were formed to pool the costs and risks associated with research and new product development, to handle distribution and marketing, and to build contract manufacturing. More critically, however, alliances were formed in an effort to establish their own de facto standards for hardware, software, network, or other architectures, sometimes in competition with Intel's and Microsoft's (Dedrick & Kraemer, 1998, pp. 59–60).

These alliances tended to be focused, ad hoc, and easily shed when their purposes had been served. They were organized around precise substantive issues—designs, implementations, service or distribution arrangements, and the like. The inherent open-endedness of a well-designed architectural system could accommodate multiple alliances at different times at different points in a system. Alliances in the U.S.-dominated PC industry were less confining than the long-term relationships observed in the Japanese industrial structures. The Wintel alliance between Intel and Microsoft was not always in evidence. The ability of AMD to compete with Intel in the market for PC microprocessors was due to Microsoft's assistance and certification. Similarly, Intel continued to search for new operating systems that used its chips in order to free itself from its dependency on Microsoft. They cooperated when it was in their interest, but distrusted each other and actively subverted the other when that seemed desirable.

Finally, the rise of Wintelism made it possible for national supplier networks to become global production networks. Because of the modular and open nature of PC technology, PC assemblers could now locate wherever needed to service regional markets. They sourced components from anywhere in the globe that provided the best product at the best price. As U.S. firms focused and specialized on creating new products in the context of standards competitions at home, they looked (often abroad) to other firms to provide everything else needed to bring new products to market. This meant that firms in the industry had to adopt a global perspective (often at the expense of latent nationalistic tendencies) in order to remain internationally competitive.

To describe global production networks in the electronics industry, Borrus and Zysman (1997) adopted the term *cross-national production networks* (CPNs): “CPN is a label [applied] to the consequent disintegration of the industry’s value chain into constituent functions that can be contracted out to independent producers wherever those companies are located in the global economy” (Borrus & Zysman, 1997, p. 141). In fact, CPNs permit and result from an increasingly fine division of labor “in which different value-chain functions are carried on across national boundaries by different firms under the coordination either of a lead MNC for its own production or of a Production Service Company (PSC) who manages the production value chain for clients” (Borrus & Zysman, 1997, p. 153).

Such global networks have occurred in the face of the general shift of hardware production to East Asia. To produce a PC, for example, a firm might use specialist producers of memories from South Korea, computer displays from Japan, printed circuit boards assembled in China, disk drives from Malaysia, digital design and final assembly services in Taiwan, software from Bangalore, and process development technology from Singapore. This move may be initiated by the desire to cut costs. However, CPNs are not principally about lower costs as such, nor about access to markets and natural resources, although these objectives may have motivated initial investments. Rather, they are about the emergence of locations that can deliver different mixes of technological capability.

Once in existence, Wintelist producers keep reconfiguring their CPNs and the existence of CPNs facilitates further experiments in Wintelist strategies. A Wintelist firm can easily subcontract production, even across national boundaries, without worrying about the possibility that contract suppliers will develop incompatible technologies. In markets where architectural standards are dominated by Wintelist firms, there is little incentive or temptation to develop new, incompatible standards. On the contrary, all the incentives go the other way.

THE ROLE OF THE REGULATORY STATE

The U.S. state has played an important role in generating Wintelism. It is often considered to be a *regulatory* state, in contrast with the *developmental* states of East Asia—particularly of Japan and South Korea—that play active roles in industrial matters. U.S. regulatory policies encouraged the value-chain specialization with open-but-owned standards that are the hallmarks of Wintelism, greatly contributing to the success of U.S. firms in the global PC computer industry.

There was a clear national security rationale for the defense-oriented industrial policies of the U.S. government after World War II, especially in policies directed toward the computer industry (Ergas, 1987). American-style industrial policy was more successful in establishing a strong domestic computer industry than the civilian-oriented strategic technology programs of other governments. Large expenditures for basic research without any clear industrial applications served as the foundation for future commercial development. Computer technologies created in military research programs were spun off into commercial products. This largely unplanned diffusion and sharing of technology resulted in first-mover advantages for the U.S. computer industry (Alic, 1992; Sandholtz et al., 1992; Bingham, 1998).

U.S. public investments in early computer research and development during the 1950s and 1960s were mostly controlled by the Department of Defense. The Defense Advanced Research Projects Agency (DARPA), created in 1957 in the wake of the launching of Sputnik, was an agency that funded dual-use technological innovations while emphasizing the pursuit of defense interests (Flamm, 1987, 1988). IBM’s entry into electronic computers, for example, was largely underwritten by military contracts. IBM’s building of computers for the U.S. military’s SAGE system accounted for about half of its total computer revenues throughout the 1950s. Military pressure for reliability and miniaturization was also a major driver in the early days of the semiconductor industry, and in the early years of the industry, the military absorbed almost all the semiconductors American firms could produce.

By the early to mid 1960s, the commercial mainframe computer market was large enough for both computer and semiconductor firms to no longer be dependent on sales to the U.S. Department of Defense. The needs of commercial users far outweighed those of military users in the development of new computer technology from that point on. However, the Department of Defense continued to fund research in advanced computing technology. This was particularly important as the United States moved to deploy highly complex weapons systems like the network of ICBMs and submarine launched missiles with nuclear warheads that were supposed to deter a Soviet nuclear attack. The Department of Defense partially funded the development of the UNIX operating system and what later became the Internet in the late 1960s and early 1970s.

In 1986, a research and development consortium called Semiconductor Manufacturing Technology (Sematech) was created to deal with fears of loss of international competitiveness in the semiconductor industry. When the Japanese attacked the American memory chip market during an industry recession in the early 1980s, the U.S. Congress agreed to appropriate $100 million per year to Sematech annually through DARPA. Sematech projects were funded jointly by DARPA and member firms with the firms contributing at least 50% of the costs of each project. Sematech's primary goal was to help the industry prevent further loss of market share in semiconductors to Japan's integrated electronics companies. Between 1987 and 1994, Sematech invested $1.5 billion in generating new and better semiconductor production technologies. Sematech represented a new departure for U.S. industrial policy, and was the subject of much partisan political squabbling. Nevertheless, it enjoyed bipartisan Congressional support and its funding continued mostly unaffected by partisan battles through the Reagan, Bush, and Clinton administrations (U.S. Congress, 1990; Spencer & Grindley, 1993; Grindley et al., 1996; Nester, 1997, chap. 3).

In order to understand the evolution of U.S. government policies toward the computer industry, we need to look beyond the conventional boundaries of industrial policy—industrial targeting, subsidies, and R&D programs—to the regulatory policies—especially antitrust enforcement, and intellectual property rights protection—that played a critical role in generating Wintelism.

The U.S. government, by strictly enforcing antitrust and fair competition laws, made important, but often largely unrecognized, contributions to the rise of Wintelism. In fact, U.S. antitrust policy enforcement in the postwar period has been considerably more stringent than that of Japan or most Western European economies. U.S. antitrust enforcement introduced competition into the domestic markets for computers, telecommunications services and equipment, and helped to lay the foundation for the later emergence of Wintelism.[10]

The U.S. Department of Justice, for example, enforced antitrust and fair competition laws in the 1960s against IBM, the dominant firm in the mainframe computer industry, and tried to prevent IBM from monopolizing the market.[11] The main impact of the antitrust case on IBM was to push IBM to unbundle its software and peripherals. In June 1969, IBM announced its decision to unbundle systems previously sold only as a single package of hardware, software, and services (Fisher et al., 1983, pp. 11–12).

Except for the very significant unbundling of peripherals and software, the 1960s antitrust action and the other resulting legal battles had little direct impact on industry competition. However, in terms of lost management time and stress, as well as an annual legal bill that went up into the tens of millions of dollars, the cost of contesting the antitrust case had an indelible impact on the top management of IBM. In the 1980s, antitrust considerations had an impact on defining the company's relationships with its smaller suppliers and competitors. Some industry analysts explain IBM's supine attitude toward small suppliers of PC components and software as a conditioned reflex ingrained by a decade spent in antitrust courtrooms (Ferguson & Morris, 1994, pp. 11 and 26).

The U.S. government's antitrust actions were central in fostering the growth of both the semiconductor and packaged software industries and encouraging value-chain specialization in the computer industry. In other words, U.S. antitrust policy helped to foster the emergence of computer component suppliers whose primary activity was selling computer components to producers of final products. The significance of the growth of independent components producers for the emergence of Wintelism cannot be exaggerated. They undermined the logic of competition rooted in vertical control of technology, and pioneered the gradual process of horizontal segmentation in the computer industry. The horizontally integrated industry structure very likely could not have emerged except under cover of the U.S. antitrust policy umbrella.

During the 1980s and early 1990s, the U.S. government seemed to be relaxing its antitrust policies, especially in sectors with strong R&D and strong foreign competition; owners of intellectual property rights benefited from a more benign judicial attitude (Merges, 1996). But recent actions taken by the U.S. Department of Justice and the Federal Trade Commission (FTC) suggest a revival of interest in stricter enforcement of antitrust and fair trading laws. Although the FTC dropped its investigation of Intel, the Department of Justice vigorously pursued and won its antitrust case against Microsoft (although the decision is still under appeal). It is possible that the end result will be a splitting up of Microsoft so that the operating systems and applications software businesses are in separate and independent firms.

The U.S. government also played an important role in protecting intellectual property rights of Wintelist firms, especially at the international level. Intellectual property has been seen as a key asset for modern corporations with very important ramifications for industrial strategy. As Robert Merges holds,

> Intellectual property determines the degree of legal shelter an incumbent can count on. Strong protection, like a brick wall, protects such as incumbent from the winds whipped up by potential entrants, while weak protection is more like a tent—it helps but cannot be relied on when the winds get too strong. (Merges, 1996, p. 285)

The U.S. government has long recognized the importance of protecting intellectual property in industry as a way of encouraging technological innovation. The history of computer program-related intellectual property legislation since the 1970s suggests that the U.S. Congress was committed to establishing new intellectual property protection regimes for both computer hardware and software.

For example, the National Commission on New Technological Uses of Copyrighted Works (CONTU), which Congress established in 1974 to investigate whether copyright protection was needed for computer software programs, concluded that copyright protection should extend beyond the literal source code of a computer program. The CONTU report resulted in passage of the 1980 Computer Software Copyright Act (Haynes, 1995, p. 254; Samuelson, 1993, p. 289).

Congress also created new safeguards for chip-related intellectual property, the model of which can be found in the Semiconductor Chip Protection Act (SCPA) of 1984. The SCPA provided a *sui generis* approach to chip protection and extended coverage to a major new technology deemed vitally important to the U.S. economy. The SCPA also provided an innovative statutory solution to the problem and contained procedures to encourage protection in foreign countries through bilateral negotiations (Leaffer, 1991, p. 290).

Since these intellectual property laws provided the creator of an original work with exclusive rights, the intellectual property owner could enjoy a temporary monopoly on the use of his or her property. Intellectual property rights rewarded innovation and encouraged research by allowing the owner to reap the benefits of his or her labor and creativity for a limited period of time, but possibly at the expense of creating the potential for persisting monopolies in major technology markets.

In this respect, strong intellectual property protection might conflict with antitrust policies (Gordon, 1996, pp. 171–173). In fact, antitrust laws shared the goal of promoting innovation and consumer welfare, but they accomplished this by prohibiting certain actions that might reduce competition. The monopoly on a work or an invention, created by the intellectual property laws' broad grants of exclusive rights, was at times antithetical to the antitrust concept of open and fair competition. Antitrust laws assumed that imperfectly competitive markets might not create as many incentives as competitive markets for innovations on the part of competing firms. Thus, the monopoly power inherent in the intellectual property laws was sometimes at odds with the policy of disallowing market dominance. In short, there was a conflict, and often a source of legal disputes, between protecting intellectual property to reward innovation and maintaining competition in markets where innovation occurred.

To summarize, we called attention to antitrust enforcement and intellectual property protection as policy instruments more important to the rise of Wintelism than the traditional instruments of industrial policy such as subsidies and the creation of R&D consortia. In the case of the U.S. PC industry, we observed a shift toward governmental policies with less interventionist and more regulatory tendencies. The relationship between the government and private economic factors in the United States was obviously less hierarchical than that found in most East Asian or West European economies. Regulatory policies played a key role in encouraging horizontal industrial segmentation and competition in architectural standards. This is consistent with our theoretical argument that decentralized governance is a better fit with Wintelism than centralized governance.

THE RISE OF A NEW INDUSTRIAL PARADIGM

Success or failure in the PC industry depended on the match between properties of PC technologies and national institutional arrangements. The technological properties of the PC—a loosely coupled system with high causal complexity—were consistent with decentralized governance structures, horizontal industrial segments, and a modified regulatory state. The U.S. PC industry succeeded in creating a new industrial paradigm called Wintelism, which was potentially comparable to the British industrial model in the 19th century, Fordism in the early to mid 20th century, and Japan's so-called Toyotaism of more recent vintage.

In our view, the U.S. success can be explained in two ways. First, adjustment of American institutions in response to increased competition from other industrialized countries—especially Japan—helped to assure the creation of Wintelism. We agree with Borrus and Zysman that Wintelism "has been spun out principally by American firms responding to international competition within the confines and logic of the American market and its particularly defined political rules" (Borrus & Zysman, 1997, p. 141). However, the regulatory role of the state in the United States was also modified to better protect intellectual property and assure competition in computer markets (Hart & Prakash, 1997). Both business and political interests in the United States deliberately moved the system toward one that was more efficient in encouraging innovations and businesses during the transition to the PC era.

Second, the U.S. did not have to move very far to change its government policies and industrial governance structures so that they fit the requirements of the emerging industries. Other countries, including Japan, were not as fortunate in this regard. Japan had been struggling for years to adapt to the requirements of markets that depend on architectural competition. To adapt successfully, it had to change many deeply ingrained policies (e.g., in education, antitrust enforcement, and the governance of the financial sector). The political costs of doing this were obviously quite high. In short, preexisting U.S. institutional conditions permitted Americans to succeed in the Wintelist sector within a framework of path-dependent learning, whereas other countries such as Japan had to engage in revolutionary learning in order to create the proper competitive environment.

Our characterization of governance structures in the U.S. computer industry parallels in important ways the argument of Robert Gilpin that fragmentation is a general feature of the American system of political economy. Robert Gilpin argues:

> Corporate governance in the United States is characterized by extensive fragmentation and an overall lack of policy coordination at both the national and, to a lesser extent, the firm level. As in the case of the government, a primary motive behind this fragmentation of corporate organization is to prevent the concentration of power. . . .the American system fits the neoclassical model of a pure competitive model based on price competition and in which firms seek to maximize profits (Gilpin, 1996, pp. 419–420)

In particular, the American science and technology (S&T) infrastructure—producing human resources and technological knowledge—may be uniquely well suited for the institutional requirements of architectural standards competition in new technologies. For example, the domestic system of higher education in the United States appears to provide a much thicker basis than those in Japan or Europe of appropriate human resources for the transition from mainframe computers to PCs. American institutions of higher education have closer links with government-funded research in the computer sector than those of Western Europe and East Asia. American universities have maintained closer relationships with private corporations in producing and sharing technological knowledge. In fact, the organizational and disciplinary flexibility of U.S. universities in computer science has not been matched in any of the competing economies. This S&T infrastructure has been supported by a unique American technological culture encouraging breakthrough-type and creative-but-risky innovative attempts in the PC industry (Mowery, 1996, pp. 306–307; Nelson, 1998, p. 321).

The U.S. success in fostering Wintelism provides an important key to an explanation of the recent resurgence of U.S. international competitiveness. The resurgence of U.S. international competitiveness on the basis of its relative strength in the new leading sectors—computers and other information industries—is in a sharp contrast to the 1980s and early 1990s when the relative decline of U.S. international competitiveness in automobiles, consumer electronics, and semiconductors was a major topic of debate. In effect, the rise of Wintelism enabled U.S. firms to determine anew the rules of the game in a new mode of competition: one that grew out of a distinctively American business/government environment that was adapted to take advantage of new challenges and opportunities.

In the PC industry, U.S. firms led the industry overall and dominated many related segments including microprocessors, operating systems, and packaged applications where control over standards was critical. Throughout the PC era, U.S. firms held the greatest share of world shipments for PC systems. Among the top 10 PC makers, "U.S. firms held a 59% share of the world market in 1985 and still held 40% in 1995" (Dedrick & Kraemer, 1998, p. 58). In microprocessors, most of the highest value-added design, engineering, and wafer fabrication activities took place in the United States. "U.S. companies still control about 75% of the software industry overall, and they have virtually 100% of the operating system market. The vast majority of that software is still developed in the United States" (Dedrick & Kraemer, 1998, pp. 63–64). U.S. firms were able to set global standards because they not only had the ability to maintain and expand their spheres of control, but also were supported by a modified regulatory state.

The question arises as to whether Wintelism is unique to the American institutional setting or can be easily adopted (or adapted) in other nations. We would argue that Wintelism is a new industrial paradigm that will become more general and diffuse to other nations over time. However, because nations clearly differ in their institutional capabilities to adjust to the rise of Wintelism, the adjustment will not always be easy. In this process of fitting institutions to technological requisites, some nations may succeed because they can easily adjust prevailing institutions to a new technological system. Some countries may fail to do so, however, because of institutional inertia or other constraining factors.

CONCLUSION

The development of the PC industry gave rise to a new mode of technological competition called Wintelism where competition and control over architectural standards became more important than the acquisition of advanced manufacturing capabilities. This new type of competition pressured nations everywhere to restructure their industrial governance and to carve out a new, less intrusive role for the state in the economy. The technological nature of PCs and related industries meant that nations had to adopt decentralized systems of industrial governance and a modified regulatory state to compete effectively. The experience of Microsoft, Intel, and the U.S. PC industry was, in our view, illustrative of a broader trend.

Wintelism originated in the transition from mainframes to PCs in the computer industry and as a U.S. response to increased competition from Japan in the 1980s, but we are now observing another transition in the computer industry. Since the early 1990s, there have been signs of the growing importance of a combined computer and telecommunications industry that increasingly revolves around global network infrastructures (Moschella, 1997). As this network-centric era begins, the prospects for new market leaders and new types of power are once again topics of speculation and research. The critical question that arises here is whether the current shift toward networked computers will result in the same kinds of fundamental changes across a wide range of activities and businesses that characterized the rise of Wintelism or whether Wintelism will simply adapt itself to the new world of network computing.

NOTES

1. It should be noted that Borrus and Zysman were strongly influenced by the ideas expressed by Grove (1996). Grove focused on the shift from vertical to horizontal integration in the computer industry; Borrus and Zysman attempted to generalize this observation to other manufacturing industries.

2. According to Kitschelt, Perrow's concept of coupling is in the same context as Williamson's concept of *asset specificity*. "Assets are considered highly specific if they are committed to a particular location, production process, or customer. In other words, high asset specificity establishes *tight linkages* (in Perrow's sense) between different elements and stages in the production process, whether it is based on purely technical or purely economic conditions, whereas low asset specificity established *loose linkage*" (Kitschelt, 1991, p. 464).

3. Kitschelt also places Williamson's concepts of uncertainty and frequency of interaction between suppliers and customers in the same context as Perrow's concept of causal complexity. "Uncertainty in contractual linkages has a technical and an economic face. High uncertainty often stems from the *complex causal interaction* among agents and techniques involved in the production process and requires, in Perrow's sense, decentralized intelligence and the autonomy of professionals. Conversely, low uncertainty is generally associated with *linear causal linkage*. In complex interactive production processes, it is difficult to specify contracts fully in advance and hence to enforce them. These circumstances also enable self-interested actors to take advantage of underspecified contracts by opportunistic behavior" (Kitschelt, 1991, p. 464).

4. Based on his two criteria of technological systems—coupling and complexity—Kitschelt distinguishes five technological clusters from Mark I to Mark V technology, and matches them to possible efficient governance structures or favored institutional arrangements. Kim and Hart (2001) modified Kitschelt's categorization and created six types of distinct technological systems in all. These six types of technologies correspond to the empirical presence of *the leading sectors*—or the cyclical development of technological innovations—in the history of industrialization. PC technology, as discussed later, is the latest technological system of the six.

5. Computer technology is comprised of hardware (all the physical equipment of computers), firmware (embedded software in programmable microchips), and software (a set of instructions that tells the electronics system how to perform tasks).

6. This holds, by the way, even for computer languages like Java that are supposed to be platform independent. That is, even though the software might work on different platforms, for it to work optimally the code still has to be different for different platforms.

7. Kim and Hart (2001) argue that standards competition is a new mode of competition in the global computer and electronics industry, and interpret it as a new mode of power in the global political economy. To learn more about their conceptualization of the new mode of power in the global political economy, see Hart and Kim (2000).

8. More than one segment in the horizontal vale-chain tend to be located in a region developing a broader industrial cluster, as is the case with Silicon Valley, which produces computers, semiconductors, semiconductor equipment, networking equipment, disk drives, printers, and software. The notion of industry clusters is extremely valuable in understanding the evolution of computer production in the United States. At various times, some analysts have forecast the decline of Silicon Valley, brought about by Japanese competition, high wages, movement of production offshore, or overregulation. So far, Silicon Valley companies have moved many activities to other locations, both in the United States and abroad, but the Valley remains the undisputed center of technology creation for the computer industry (Dedrick & Kraemer, 1998, pp. 219–220; Saxenian, 1994; Cringely, 1993).

9. Intel's strategy to establish its brand name identity was initiated by Intel Japan that adopted the new *Intel In It* program. This Intel Japan-sponsored brainchild has earned the hands-down praise of the U.S. head office, which has instigated a similar campaign on the American market under the catchphrase of *Intel Inside* (Howe, 1995).

10. In the United States, the Antitrust Division of the Department of Justice (DOJ) and the Federal Trade Commission (FTC) have the job of enforcing antitrust legislation. The DOJ is basically a prosecuting body, and has the authority to mobilize FBI agents for its investigations. The FTC can be described as an executive branch regulatory committee independent from the command of the President. It consists of a five-person committee and an executive office, and has authority to investigate violations and render judgments.

11. As a former U.S. Government antitrust economist, Richard DeLamarter, describes in his book *Big Blue*, IBM lived on the edge of antitrust law, using highly aggressive tactics to drive rivals out of the punch-card business in the 1920s through 1950s (DeLamarter, 1986).

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