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Hardware Institutions for *Software* Technologies:
The Japanese Model of Industrial Development in the Personal Computer Industry*

Sangbae Kim

This paper attempts to explain why Japan has largely failed to meet unique technological challenges in the field of computer software while it has achieved remarkable success in its technological counterpart—computer hardware. What makes this research question puzzling is the fact that Japan has employed pretty much the same industrial policies and institutions for promoting both sectors, nevertheless producing divergent results. Existing neo-institutional approaches to industrial competitiveness are inadequate for explaining this puzzle with respect to "sectoral variation" in the effectiveness of industrial policies and institutions. I suggest that the theory of "technological fitness" is more useful for helping us to understand the relevance of industrial institutions—and further institutional adjustment strategies—in relation to the underlying technological conditions of industrial sectors. In this view, Japan has largely failed in computer software because it has continued to rely on its "hardware institutions" in competing for software technologies.

Keywords: Computers, Institutions, Adjustment, Japan, The United States

1. INTRODUCTION

Japanese industry is perhaps the most striking success story in the global economy in the latter half of the twentieth century. Nowhere has this industrial success been more evident than in the field of hardware components and peripherals for personal computers (PCs), such as dynamic random access memories (DRAMs), flat panel displays, CD-ROM drives, floppy disk drives, optical steppers for semiconductor fabrications, and silicon ingots wafers. However, Japan has never been competitive in the key areas of computer architecture and software; it has lagged behind the United States in the development of microprocessors, operating systems, and packaged software, which have come to shape the development of PC systems through the ongoing definition of architectural standards. In this article, I analyze why Japan has failed to meet unique technological challenges in the field of *computer software* while it has achieved remarkable success in its technological counterpart—*computer hardware.*[1]

What makes this research question puzzling is the fact that Japan has employed pretty much the same industrial policies and institutions for promoting both industrial sectors, while nevertheless producing divergent results. Starting in the late 1960s, for example, the Japanese government brought all the tools of its renowned industrial policy—industrial targeting, joint industry-government research and development (R&D), protectionism, and financial incentives—to bear on the task of developing the world's most formidable

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[1] Scholars in economics and business have examined this puzzle in the Japanese computer and software industry. Exemplary works include Cusumano (1991); Fransman (1995); Cottrell (1996); Baba et. al. (1996); Itami, et al. (1996); Dedrick and Kraemer (1998); West and Dedrick (1999).

computer industry (Anchordoguy 1988; 1989). In fact, by the late 1970s, these industrial policies, in collaboration with key industrial institutions, were very effective at generating innovation and promoting business in the computer hardware sector; the same policies, however, have proven ineffective for adequate nurturing of the computer software sector as it advanced through the 1980s and into the early 1990s. Why would the same industrial policies and institutions, which had worked for computer hardware, not prove successful for the development of a competitive computer software sector?

Existing neo-institutional approaches—a dominant tradition in the international political economy (IPE) analysis of industrial competitiveness—are inadequate for explaining this puzzle concerning "sectoral variation" in the effectiveness of industrial policies and institutions.[2] In this article, therefore, I offer the theory of "technological fitness," which suggests understanding the relevance of industrial institutions and further "institutional adjustment strategies" in relation to the underlying technological conditions of certain industrial sectors. I seek to explain why hardware and software technologies require different institutional arrangements for their efficient industrial performance. I argue that the existing Japanese policies and institutions *fitted* the institutional requirements of computer hardware technologies; but that they *did not fit* those of computer software technologies, which clearly require different governance structures from those we found in Japan. I use Japan's contrasting experience in the software and hardware sectors to demonstrate how a state should adjust its national conditions to the institutional requirements of a changing technological environment at the sectoral level and how the state's institutional adjustment strategies are constrained by its pre-existing institutional conditions at the national level.

2. JAPAN'S FRUSTRATION IN PC ARCHITECTURE AND SOFTWARE

As Japan's electronic giants had vanquished most of their American competitors in consumer electronics by the late 1980s, many in the United States feared that America's computer industry would meet the same fate; they predicted a rapid Japanese advance to global leadership in PCs throughout the 1980s and 1990s. The PC seemed to offer an excellent opportunity for Japanese companies to compete in global markets, capitalizing on their manufacturing prowess to produce standardized, high-volume products. By the early 1990s, however, this fear that Japanese manufacturing prowess would sweep away the Western PC industry did not materialize (Finan and Williams 1994; Itami 1998).

Although Japanese computer makers are among the largest in the world, they have never dominated global PC markets the way their counterparts have done in consumer electronics. They have only been able to compensate for their global weakness by their strong positions in their domestic PC market. Among the top five PC system producers, for example, which occupied 35.8 percent of the global PC market in 1995, four were U.S. companies and only the fifth was Japanese; U.S. companies had 31.1 percent of the global PC market—Compaq 10 percent; IBM 8 percent; Apple 7.8 percent; and Packard Bell 5.3 percent—and NEC, the largest Japanese PC maker, had only 4.8 percent of global market

[2] A group of scholars in IPE explains international competitiveness in terms of national-level institutional variables. They spotlight how variations in industrial outcomes are determined by different domestic features of national political economies, and how certain nations can be bequeathed relative advantages over others in international competition (Katzenstein, ed. 1978; Katzenstein 1985; Zysman 1983; Zysman and Tyson, eds. 1983; Hall 1986; Hart 1992).

share (Dedrick and Kraemer 1998: 61). In fact, most of the worldwide revenues of Japanese computer companies came from the dynamic Japanese PC market. About 80 percent of Japan's PC production was for the domestic market throughout the 1990s. Moreover, Japan's problems were highlighted by a decline in PC production in the early 1990s, reversing a decade of rapid growth. Total output declined by 17 percent from 1990 to 1992, before rebounding slowly from 1993 to 1996. Total production again entered into decline, however, from 1996 to 1997 by 5.7 percent (Table 1).

Table 1. Personal Computer Production in Japan, 1988-1997

(Unit: Thousand)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Total	2,192	2,405	2,660	2,309	2,207	3,233	4,479	6,919	8,664	8,174
Domestic	1,375	1,657	2,066	1,903	1,766	2,382	3,348	5,704	7,192	6,851
Export	817	748	594	406	441	850	1,131	1,215	1,472	1,323

Source: *Pasocon Hakusho* (Personal Computer Whitebook). Various Years

One problem of critical importance to the Japanese PC industry is the way in which Japanese PC makers failed to take the initiative in creating and maintaining *de facto* PC standards in the global arena. On the contrary, from the beginning, Japanese PC makers established their own PC architectural standards, which were incompatible with global PC standards as well as with each other's systems. This architectural incompatibility originated from Japanese firms' competitive strategies as well as from the technological incapability of the industry in handling Japanese language characters in the early years of Japanese PCs (Kim 2000, ch.4). This situation did have one advantage in that it shielded the Japanese computer industry from foreign competition for a long time. In the long run, however, it has put Japanese computer markers at a disadvantage in the global market because PC systems developed for Japan's domestic market have very little appeal abroad.

A market challenge of central importance came to the fore in the early 1990s when substantial technological improvements in processing Japanese-language characters—known as the DOS/V operating system—were achieved by IBM Japan, and, thus, PCs made for the global market were capable of processing the Japanese language quite adequately. U.S. computer makers were quick to capitalize on this technological development. For example, Compaq with IBM-compatible PCs—which were *de facto* global standards—launched sales campaigns in Japan featuring low-priced PC models, forcing open Japan's closed door as a PC standard island.

IBM-compatible PC standards have gradually penetrated into the architectural layers of Japanese PCs—particularly into operating systems and application programming interfaces (APIs)—in which a Japanese PC maker, NEC, had been dominant for more than a decade with its proprietary standards, PC-98 series. By the early 1990s, all Japanese PC makers but NEC had joined the IBM-compatible DOS/V camp; IBM Japan and Toshiba were IBM-compatible makers from the beginning; Fujitsu, the largest computer manufacturer in Japan, joined in 1993; Seiko Epson, which had been a clone maker of NEC's PC-98, joined in 1994. NEC dramatically lost market share throughout the early 1990s, from 52 percent in 1992 to 29.9 percent in 1997; finally, it was forced to relinquish its proprietary PC standards so as to converge upon the IBM-compatible PC standard in 1997 (Table 2).

Table 2. Share of Japan's PC Market by Company, 1991-97

(Unit: Thousand for Total PC Production, % for Market Share)

	1991	1992	1993	1994	1995	1996	1997
NEC	52	52	49	43	40	33	29.9
Seiko Epson	9	7	6	5	3	n.a	n.a.
Fujitsu	8	8	7	9	18	22	23.6
IBM Japan	7	8	7	10	10	11	11.4
Toshiba	9	6	6	4	4	6	8.5
Apple Japan	6	9	13	15	14	10	5.4
Other	9	10	12	14	11	n.a.	n.a.
Total	2,309	2,207	3,233	4,479	6,919	8,664	8,174

Source: Dedrick and Kraemer (1998: 83) [for 1991-96]; IDC Japan data [for 1997]; and *Pasokon Hakusho*, 1998-99 [for total production from 1991 to 1997]

Japan's frustration in this PC standards competition vividly reflects the fact that Japan has completely failed to establish a presence in the key areas that have served to define PC architectural standards—microprocessors, operating systems, and packaged software. Of the top five microprocessor makers in 1996, Intel was the leader with 83.4 percent of market share; AMD with 8.5 percent, IBM with 4.1 percent, Motorola with 1.9 percent, and Texas Instruments with 1.1 percent. NEC, the first Japanese microprocessor developer, was not ranked among the top five, having a relatively negligible market share. Of the top three which dominated 95 percent of global market share for operating systems in 1995, Microsoft was at the top with 80.1 percent share; Apple 8.2 percent; and IBM 6.7 percent. All were American companies; Japanese computer makers have virtually been shut out of the operating system software business. The Japanese have also trailed behind in packaged software production for the global market. Japan had a 9.2 percent of world packaged software market share in 1991, 9.3 percent in 1992, and 9.7 percent in 1993.

Two American companies, Microsoft and Intel, have all but monopolized the key areas of PC architecture and software, and have established a *de facto* global PC standard since the early 1980s. The dominance by Microsoft and Intel over PC standards competition and the subsequent transformation of the computer industrial structure are conceptualized as "Wintelism," a term derived from the "Windows" of Microsoft's operating system and "Intel" (Borrus and Zysman 1997).

In the global PC industry, for example, Microsoft's operating system and Intel's microprocessors are not only superior pieces of equipment that "product competition" might hope to match or surpass with a reasonable effort. Rather, for some years now, they have served as structural constraints—*the rules of the game*—which every firm entering the industry has had to accept. In this sense, Wintelism presents the rise of a new mode of competition in the global computer industry, in which the cutting edge lies not in piecemeal technological innovations, but in the establishment of *de facto* technical standards that inventing firms are able to protect via intellectual property rights (Arthur 1996; Hart and Kim 2000; Kim and Hart 2002).

To summarize, by the late 1990s, Japanese PCs all used the same microprocessor made by Intel and the same operating system made by Microsoft (or IBM Japan) and largely relied on application software imported from the United States. Japan's heavy dependence on the United States in these critical segments of PC systems meant that, despite strenuous efforts to defend their own PC standards, all Japanese makers were eventually forced to conform to the global standards, NEC being the last in 1997.

3. NEO-INSTITUTIONAL EXPLANATIONS OF COMPETITIVENESS

To explain Japan's industrial success, neo-institutional scholars in IPE have highlighted Japan's distinctive institutional features, which are seen as operating differently than those of other capitalist countries. These unique institutional features have been seen as bolstering Japan's industrial competitiveness, often called "the Japanese model of industrial development," or "the Japanese industrial model"—characterized by the "developmental state" typified as industrial policy, the "networked" relationship among firms known as the *keiretsu* system, and other unique industrial institutions such as "manufacturing-oriented" science and technology (S&T) infrastructure. From the neo-institutional perspective, the Japanese industrial model clearly accounts for Japan's industrial success in various sectors such as steel, autos, consumer electronics, and semiconductor memories (Johnson 1982; Johnson ed. 1984; Samuels 1987; Hart 1992; Gerlarch 1992; Fong, 1990, 1998).

Japan's recent economic slump, beginning in the early 1990s, however, has raised the question of why renowned Japanese policies and institutions cannot produce as successful industrial outcomes as they had previously achieved. The Asian financial crisis of 1997 further reinforced scholars' doubts about the effectiveness of Japanese policies and institutions as a model for industrial development elsewhere. For some, Japan is already seen as a stark case of a once-successful system that has already "soured" (Katz 1998). In other words, the advantages from Japan's unique institutional conditions no longer serve to boost the industrial success of the nation; rather, the once-successful Japanese system fetters industrial performance in some critical sectors. Taking the case of the software industry, for example, Marie Anchordoguy argues, "The institutional arrangements of Japan's catch-up system are the primary cause of Japan's software firms' competitive weakness. The very arrangements that help explain Japan's success in steel, machine tools, semiconductors, and computer hardware are found to be the source of its weakness in software" (Anchordoguy 2000).

This question of why the Japanese industrial model is not working now, whereas it had worked well before, is a highly complex one, with many different avenues. Within the neo-institutional tradition, an explanation focusing on Japan's competitive position change in the international system has gained great popularity. Glenn Fong, for example, relies on a seminal work by Alexander Gerschenkron (1962) and explains "differences and changes in the competitive positions of nations—for instance, early versus late industrializers, successful followers or challenged pioneers—encompass distinctive imperatives and requirements for government institutions and state-industry relations" (Fong 1998: 339-40). By the mid-1980s, in his view, Japan's competitive position had shifted from a "pursuer after the pioneer" to a "follower at the frontier" in a broad array of high technologies, and, thus, Japanese institutional arrangements created during its attempts to catch-up became less effective and even dysfunctional. In particular, this competitive position change dissipated what Gerschenkron has called "the advantages of backwardness" that Japan had enjoyed during the catch-up period.

The imperative of moving ahead now that Japan has attained world-class competitive status is putting great pressure on Japan to undergo fundamental changes to its political and economic system. Japan is also coming under international pressure to change its institutional arrangements created during the catch-up phase. The current debates reflected in much of the academic and popular literature suggest that Japan needs to develop a market-based system as discussed by "the convergence theory" in the literature on globalization (Berger and Dore, eds. 1996). From this perspective, adjusting the Japanese domestic system through domestic deregulation and trade liberation would benefit Japan. However, Japan has not yet been successful in adjusting its political economic system to a point where it is able to assure competitive success at the technological frontier.

Doubtless, existing national-level analyses from neo-institutional perspectives do serve to capture certain important aspects of key problems associated with the Japanese industrial model. Neo-institutional explanations are inadequate, however, in explaining cross-sectoral variations of industrial outcomes within a national setting. The neo-institutional perspective has usually focused, for example, on Japan's national institutions as explanatory variables in the key industries where Japan has been successful. The "modified" neo-institutional perspective, in turn, focuses on the changing features of those national institutions—caused by international systemic factors—and explains changes in the level of Japan's national competitiveness as an aggregation of industrial performance in these industries.

Indeed, neo-institutional perspectives—in both original and modified versions—tend to adopt "holistic" stances that set their analyses at too high a level of aggregation to fit well with the reality of national patterns. The validities of "attributes of nations," which are assessed at the level of "national" competitiveness, cannot be accurately applied to diverse industrial sectors which would undoubtedly yield various "sectoral" outcomes. Holistic approaches may fail to account for considerable variations across industrial sectors. In this respect, Japan's contrasting industrial performances in the computer hardware vs. software sectors typify the sectoral variation that the holistic neo-institutional approaches cannot adequately explain.

4. TECHNOLOGICAL PROPERTIES AS A SECTORAL VARIABLE

It is my view that national-level institutional analyses should be complemented by sectoral perspectives, which attempt to explain sectoral governance structures (and further various industrial outcomes) in terms of sector-specific properties and endowments, such as markets, ownership or liquidity of capital, source of income, labor markets, technology, and so forth—either alone or in combination as independent variables (Kurth 1979; Rogowski 1989; Gourevitch 1986; Frieden 1991; Shafer 1994; Gilmore 1997). In fact, studies of Japanese industry have recently adopted sectoral perspectives, usually defining an industrial sector exclusively in terms of "market conditions" (Callon 1995; Gilmore 1997; Dedrick and Kraemer 1998; Anchordoguy 2000). Those studies argue that industrial institutions and policies must "fit" the requisites of competition in markets. Only then will policy makers and business leaders enjoy the autonomy and relative capacity to effectively formulate and implement industrial policy and corporate strategy.

While these sectoral analyses focusing on market conditions may help to explain sectoral variations of industrial outcomes, their explanations still lack analytical frameworks for understanding the institutional requirements (or efficient governance structures) of a given industrial sector. Indeed, market conditions as a sectoral variable are inadequate because similar products and services in a market may be delivered with different technologies and input factors. In this article, therefore, I rely on the idea of Herbert Kitschelt (1991), and conceptualize a sector as a technological system within a particular market segment. In Kitschelt's view, a definition of industrial sectors should be based on technological systems in order to differentiate variations of industrial governance structures within a given market. In fact, "technological properties" are one of the major sectoral variables shaping the governance structures of industrial sectors (Kitschelt 1991: 460).

Since the late 1970s and early 1980s, technological changes in the computer industry shifted the industrial focus from mainframes to PCs, and have transformed the economic characteristics, mode of competition, and institutional characteristics of the global computer industry (Ferguson and Morris 1994; Moschella 1997). For example, new standardized semiconductors (microprocessors), introduced in the late 1970s, were smaller, less expensive, and more reliable than those that had been incorporated into traditional mainframe computers. The software aspects of computer technology gradually gained increasing significance for the operation of PC systems in contrast to the hardware aspects that were dominant in the development of mainframes. In particular, the development of new PC technologies typifies the rising significance of computer architecture and software technologies, which I call "software electronics."

Software electronics technology includes computer software, micro-code, semiconductor chip designs, and other architectural standards. But it does not include hardware aspects of component or systems assembly, such as memory chips, flat-panel displays, floppy disk drives, hard disk drives, and printers, which I call "hardware electronics." Although both hardware and software electronics belong to a subset of computer technology, the two technological systems should be distinguished from each other in that they have different technological properties that require different governance structures for their maximum performance.

Most significantly for my purposes is the way in which this dramatic technological shift in the computer industry towards an emphasis on software coincided—not incidentally—with the shift of Japan's competitive position in the world economy. In other words, at approximately the same time that Japan caught up with U.S. technological leadership and emerged as a technological leader in the computer industry—particularly in the computer hardware sector—the focus in computer technology shifted not only from mainframes to PCs, but also from hardware-centered to software-centered paradigms. These two changes—Japan's positional change in the international system and the technological paradigm shift in the computer industry—are clearly interrelated; it is necessary, therefore, to attempt to distinguish the two changes in an analytical sense.

Many neo-institutional perspectives make a critical mistake by overlooking this technological shift—a sectoral variable—that defines the attributes of a particular industrial sector. Technological shifts in the computer industry—rather than Japan's overall competitive position change—are better able to explain the sectoral variations of Japan's industrial performances in hardware and software electronics, and the effectiveness (or limits) of Japanese policies and institutions in these sectors. In other words, only a sectoral focus on technological properties can clarify the fuzziness associated with national-level explanations from the perspective of neo-institutionalism.

5. ANALYTICAL FRAMEWORKS FOR TECHNOLOGICAL SYSTEMS

To distinguish types of hardware and software electronics as technological systems, and further to distinguish types of governance structures to which they are expected to relate, I rely on Herbert Kitschelt's framework, which makes predictions about efficient governance structures for technological systems.[3] 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, production steps must be done at the same location or at the same time, in a carefully coordinated fashion. In loosely coupled systems, however, each step or component of production is separated from every other step in space and time. Thus, production steps can be completely, at least theoretically, 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.

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 high levels of capital investment for local firms to be successful.

Second, the complexity of causal interaction underlies the importance of feedback among production stages that is required to keep the whole process on track. In systems with complex interaction, elements have a mutual influence on each other and engage in circular causal interactions. Thus, complex systems have large information requirements for managing the intricate flow of connections across processes. In systems with linear interaction which proceed from one stage to the next without feedback, the causality between elements is not complex. Thus, linear systems have fewer information requirements. In complex interactive systems, however, the monitoring, analysis, and correction of production processes take place in decentralized organizational units, because a centralized control would quickly become overloaded. In contrast, less complex systems with linear causality among the components are more amenable to centralized control because the straightforward intelligibility of systemic interactions reduces the probability that centralized control units will be overloaded with information processing.

This concept of causal complexity is closely related to "types of problem solving in research and development." If a technological process is in a 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, yielding fast-paced technological change with major breakthroughs followed by

[3] To develop his frameworks, Kitschelt draws on recent contributions to organizational theory in sociology, economics, and business history. 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.

small incremental improvements. However, if the technological process is in a causally linear system, then its trajectories are more 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.

According to these analytical frameworks, hardware and software electronics—as technological systems—require distinct sectoral governance structures that fit their technological properties to enhance maximum performance. In other words, the efficient possibilities of governance structures for innovations in hardware and software electronics are constrained by the institutional requirements of these technological systems characterized by the combination of coupling and complexity. Here, I adopt a parsimonious conceptualization of institutional factors and characterize governance structures by two domestic structural variables—the industrial role of the state to intervene in the economy, and the industrial organizations of private economic actors— linked to properties of the technological systems. Now, the remaining issues are to examine what properties the technological systems of hardware and software electronics have, what types of governance structures match them, and how those matches are related to the Japanese story of industrial failure in software electronics.

6. HARDWARE ELECTRONICS AND GOVERNANCE STRUCTURES

The industrial sectors in which Japan gained competitive advantages are characterized by hardware electronics. According to the above analytical frameworks, hardware electronics is a "relatively tightly-coupled" technological system. These are high-volume industries with standardized, inexpensive systems designed and assembled from low-cost, mass-produced components. They are capital-intensive industries requiring stable R&D investments in both product and process technologies. Hardware electronics is also a technological system of "moderate low-causal complexity." Because this type of technological system involves moderate knowledge intensity, its technological trajectory is generally predictable, and product advances can be substantially improved through innovations of process and product technology in incremental steps.

This area of incremental innovations with relatively heavy capital investment has long represented the greatest strength of Japanese companies. In fact, in the field of hardware electronics, Japanese companies were helped by their ability to steadily accumulate competences through increasing stable investments, and through manufacturing practices that resulted in continuous incremental improvements, or *kaizen*, as it is called in Japan (Imai 1988). In Japan, for example, a brand-new generation of semiconductor plants, which is capital-intensive, was built every four or five years with state-of-the-art process and manufacturing technology layers from high-performance computing down to low-end consumer products. And once the manufacturing process was mastered, the technology was applied to a diverse range of more advanced products. One of the best examples is Japan's development of liquid crystal display (LCD) technology, which it originally used in pocket calculators, then steadily introduced into a series of more advanced products, including televisions, notebook computers, and camcorders.

Relatively tight-coupling tends to favor large, vertically integrated, and diversified Japanese companies—which are usually members of a *keiretsu*. In other words, large Japanese industrial organizations were well suited to high-volume, capital-intensive productions of hardware electronics products because they had the financial resources necessary to make large investments in R&D and production facilities and to weather temporary downturns in the market. Of special importance was the way that Japanese companies could marshal necessary resources from within their *keiretsu* groups and count on the members of those groups as captive customers. Networks of *keiretsu* firms provided Japanese makers with various advantages in the production supply chain, product manufacturing, and technological innovations, in addition to access to capital (Odagiri 1998: 115-28). In this way, networked industrial organizations were successful at enabling "flexible mass production," characterized by the continual modification and upgrading of existing components and products yielding a constant flood of new models.

At the same time, moderately low-causal complexity tends to favor the industrial role of the developmental state. For example, the Japanese Ministry of International Trade and Industry (MITI) promoted leading-edge sectors, especially through cooperative R&D consortia, as the heart of its industrial policy: MITI attempted to reduce redundant research, accelerated technological advancement, and encouraged the firms to specialize so that they could achieve the economies of scale necessary to compete with U.S. competitors in the field of hardware electronics (Flamm 1987, 1988). Examples include the 1966 Super High-Performance Computer Project (1966-72), the New Series Project (1970-74), and the Very Large-scale Integrated Circuits (VLSI) Project (1976-79) (Anchordoguy 1988, Fransman 1990). In these R&D projects, technological properties of hardware electronics, of which technological trajectories are readily predictable, made it possible for MITI to undertake large-scale efforts targeting specific technologies with confidence that those technologies would still be relevant several years later, and to persuade other private participants to cooperate within the format of joint projects.

To summarize, Japanese industrial organizations and industrial policy—the governance structures of which match the institutional requirements of hardware electronics technology—have contributed to Japan's dramatic industrial success in DRAMs, flat panel displays, and other hardware products. Japanese industrial organizations and industrial policy attracted worldwide attention because they offered an industrial paradigm (or the "best practice" industrial model) for the hardware electronics sector, which historically outperformed existing U.S. or European industrial institutions in the same sector.

7. SOFTWARE ELECTRONICS AND GOVERNANCE STRUCTURES

Software electronics is the primary industrial sector in which Japan has lagged behind the United States. According to the above analytical frameworks, software electronics is a "loosely coupled" system. The loose coupling permits "decentralized" control over the technological system; thus, its production steps do not have to be integrated in a sequential process in time or space. The economies of scale or the requirements of capital investment for product and process technologies are not so high as with hardware electronics. Software electronics is also a "complex interactive" system. Due to its high knowledge intensity, technological trajectories of software electronics are not readily predictable with respect to time, cost, or final result. Thus, the development of new software electronics products is usually the result of trial-and-error research and breakthrough or watershed forms of innovation.

This area of breakthrough innovation with moderate capital investment represents the greatest strength of U.S. computer and software companies. In the cases of microprocessor chip design and software engineering, quality control and process improvement have not been the central focus; rather, they have distinguished themselves in terms of product invention and functionality. The greatest added value of software electronics comes from "knowing *what* to manufacture" rather than from "knowing *how* to manufacture" (Umeda 1994: 34, italics in text). In fact, knowledge-intensive products of software electronics are generally introduced by discontinuous breakthrough innovations at small-sized R&D units rather than by incremental innovations with heavy capital investment in large production facilities. A small number of American companies have acquired near monopolies in these fields of computer business with the highest levels of added value. For example, Microsoft and Intel have all but controlled the evolution of PC architectural standards; they have defined the terms of competition in the global PC industry (Borrus and Zysman 1997: 150).

In fact, since the late 1970s and early 1980s, technological properties of software electronics favored the governance structures of the U.S. computer industry, which had shifted from "vertical integration" of the mainframe industry to "horizontal integration" of the PC industry (Grove 1996). For example, the loose-coupled modularity of PC technology allowed computer firms to source parts, subassemblies, components, and peripherals from anywhere in the horizontally integrated value-chain as long as architectural standards—the underlying bond—unified all the distinctive products and functions within a PC system. The highly complex development process of software electronics, including design, coding, testing, and integration, requires "decentralized" governance structures at corporate and industrial levels that are able to handle a tremendous amount of feedback and informal communication within the firm, as well as between producers and sophisticated users.[4] In this respect, the horizontally integrated U.S. computer industry has been at the center of this transition giving rise to "decentralized" governance structures in the PC industry.

With respect to the state's industrial role, the U.S. case shows that "regulatory" policies—characterized as a *less centralized* policy means than Japanese-style industrial policy—has played a conducive role in providing appropriate governance structures for software electronics. As seen in the case of IBM's software-unbundling and more recently, Microsoft's antitrust lawsuit, the U.S. government's antitrust actions were "unintentionally" central in fostering the emergence of component suppliers that provided final assemblers with independent products of their own brand identity. It is difficult to exaggerate the significance of these components suppliers since they clearly serve to undermine the logic of "vertical integration" controlled by final assemblers, and because they have been pioneers in the transition process toward "horizontal integration" (or value-chain specialization) in the U.S. computer industry. It is very likely that this kind of horizontally integrated industry structure could not have emerged except under cover of this kind of unique U.S. policy umbrella.

Building on Borrus and Zysman's work (1997), I understand the rise of decentralized governance structures in the U.S. computer industry by using the concept of Wintelism (Windows + Intel). "Wintelism writ small" refers to the structural dominance of Microsoft and Intel over the PC architecture standards. In a broader sense, "Wintelism writ large" signifies the rise of a new "industrial model" (or "industrial paradigm") potentially comparable to the British industrial model in the nineteenth century, Fordism in the early and mid-twentieth century, and the Japanese industrial model of more recent vintage.

[4] For example, it is in this sense that software engineering is usually regarded as the field of "learning by doing" or "learning by using" (Rosenberg 1982).

Indeed, the rise of Wintelism in the U.S. computer industry goes a long way toward explaining the resurgence of U.S. international competitiveness based on the relative strength of the software electronics sector as a new leading sector.[5]

8. THE JAPANESE INDUSTRIAL MODEL IN SOFTWARE ELECTRONICS

It is obvious that technological properties of software electronics no longer reward the Japanese industrial model. Loose coupling, for example, does not reward the organized capabilities of large, vertically integrated, networked industrial organizations with economies of scale and manufacturing techniques. In the field of software electronics, technological innovation is relatively independent and sometimes discontinuous between technological elements; thus, the agile responsiveness of organizations gains priority over stability in order to foster and support this "innovative de-centricity." Japanese industrial organizations, however, remain oriented toward nurturing competitiveness through large-scale, stable investment and high-quality manufacturing. The high level of stability generated in Japanese industrial organizations does not seem to be conducive to the realization of the kind of dynamic environment called for by the PC industry. As compared with that of the United States, the Japanese system appears to have a tendency toward stagnation.

Large Japanese computer makers have been very slow in recognizing and responding to the rise of the PC era, failing to cope, for example, with the shift in standards strategies from "closed-and-owned" standards in the mainframe era to "open-but-owned" standards in the PC era. By the late 1980s, Japanese computer makers were still obsessed with an image of producing and selling mainframes—an image of beating IBM—at the very same time that they were already moving into the PC business (Fransman 1995: 182). Moreover, the vertical integration of Japanese computer makers has resulted in product development that is insufficiently responsive to consumer demand. Likewise, Japanese companies with broadly "diversified" product lines find it difficult to compete with U.S. firms that specialize in a market segment of the horizontally integrated value-chain. Problems have also been emerging for some time as a result of the relatively *closed* supplier networks of the *keiretsu*. Japanese production networks, dominated by the core company with extensive use of subsidiaries, have proven rigid and slow in attempting to cope with the accelerating demands of the PC business. A style of "*keiretsu*-wide vertical integration" has left Japanese companies that are dependent on a *keiretsu* partly isolated from dynamic global production networks, or from cross-national production networks (CPNs) that are developing throughout East Asia.

[5] Wintelism was born in the transition from the mainframe era to the PC era; but we are now observing another technological/structural transition; the computer industry is now giving way to *the network era* (or *the post-PC era*)—a new industrial phase in which the industry increasingly revolves around a global network infrastructure or the Internet. In order to establish a general theoretical basis for my argument about Wintelism, it is necessary to ask a further question as to whether the idea of Wintelism can be applied to the computer industry *beyond the PC era*. In fact, as the network era began around 1993-1994 and continues through the current period, the computer industry—or the broader information industry—once again witnesses the emergence of new market leaders, new industrial structure, and new business models. For more details of the story of Wintelism in the network era, see Kim (2000 :ch.7) and Hart and Kim (2002).

In a similar vein, high causal complexity does not reward the Japanese-style cooperative R&D projects as a means of industrial policy to promote innovations in PC technologies. In the 1980s, MITI continued to employ a strategy that it had used in its efforts to catch up in mainframes and semiconductors, and initiated R&D projects aimed at again advancing Japan to the technological frontiers of hardware performance and developing a new generation of computer architecture. The major three R&D projects undertaken in the 1980s include the Supercomputer Project (1981-89), the Fifth Generation Computer Project (1982-91) and the Sigma (Software Industrial Generalization and Maintenance Aids) Project (1985-90) (Fransman 1990; Cusumano 1991). While some successes have been claimed for each of these projects, none of them have come close to achieving the ambitious objectives set for them, and have not moved Japan any closer to controlling any key architectural standards in the computer industry.

The ideas and policies targeting "next generation" technologies in these MITI-initiated projects were not successful in cutting-edge innovation in software electronics, technological trajectories of which are not readily predictable. These R&D consortia, for the most part, remained obsessed with a vision of beating IBM's mainframes; MITI-targeted technologies soon became obsolete, however, in the rapidly changing marketplace. While MITI's R&D consortia were struggling with upgrading large-scale mainframe computers or improving the productivity of "software manufacturing," the rest of the computing world was moving toward a different idea of computing—PCs with standardized hardware components and peripherals, and with packaged software in which functionality was given priority over productivity or quality. In fact, software electronics technologies are changing too quickly for five-to-ten-year plans, and the cooperative R&D projects have been too "centralized" (or too "plan-based") to cope with the unpredictable challenges of software electronics.[6] It is natural, therefore, that Japanese companies were reluctant to participate in those R&D projects although they finally agreed to do so under MITI's pressure.[7]

To summarize, Japanese industrial organizations and industrial policy in the computer industry have not been able to provide suitable governance structures for software electronics, which obviously requires *less centralized* governance structures than what is found in Japan. From a strategic perspective, therefore, it is understandable why Japanese firms and the Japanese state have been forced to adopt *new* governance structures for the computer industry which clearly diverge from the familiar patterns of Japanese industrial success in sectors where technological properties are matched to Japanese institutional capabilities.

9. INSTITUTIONAL ADJUSTMENT AND INSTITUTIONAL INERTIA

As analyzed above, the primary "fit" between technological properties in industrial sectors and governance structures of national institutions is important in the sense that this fit provides the initial conditions that result in industrial success or failure. However, this success or failure also depends on the ability to translate these initial conditions into

[6] Interview with a MITI official.

[7] R&D consortia themselves—even if they are initiated by private actors, and are based on correct visions that can be successfully implemented—might not be an appropriate means for innovations in the field of software electronics. The failure of the TRON (The Real-time Operating-system Nucleus) Project (1984—present) provides an excellent example (Callon 1995: 113-14).

efficient sectoral governance structures (Kitschelt 1991: 480). In this sense, what is most important is "technological fitness," which refers to the ability to adjust existing national institutions to changing technological environments in industrial sectors (Kim and Hart 2001). How should the Japanese adjust their organizational structures and national institutional arrangements in order to be able to assist the industry in dealing with technological change? It at least appears clear that any institutional adjustment in the Japanese computer industry, according to the above analytical frameworks, must be oriented toward the Wintelist industrial model as a successful precedent.

In fact, there are a number of signs that the Japanese state has already engaged in institutional adjustment projects and has already attempted to adopt new governance structures in the computer industry. Since the early 1990s, for example, government regulations have been loosened so as to increase market competition. MITI recognized that software was clearly Japan's weakest sector, and that software was significantly different from other industries that MITI had targeted in the catch-up period. Moreover, Japanese private actors have already engaged in structural adjustment projects. For example, large, vertically integrated computer manufacturers are initiating adjustments in industrial organizations. They are attempting to restructure their corporate organizations, to loosen their networks of capital flows, component supply, and product distribution, and to move abroad searching for cheaper labor.

At least by the late 1990s, however, Japan's institutional adjustment in the computer industry had been insufficiently flexible for the revitalization of its floundering computer architecture and software sectors. Why did the Japanese find it difficult to adjust their institutional arrangement to the changing technological environment caused by the rise of software electronics?

To answer this question, we need to bring national-level variables back into the sectoral explanation above in terms of technological fitness. Indeed, no matter how much institutional adjustment takes place, technological fitness *per se*, without interacting with national institutional factors, cannot straightforwardly produce final industrial outcomes. To capture the nature of these national-level institutional factors, I focus, in particular, on the interplay between agent's interests and institutional structure, attempting to explain how institutions are shaped (or adjusted) by strategies choices, and, in turn, how institutions impose constraints and opportunities on strategic behaviors within these institutions. Operating within this neo-institutional view, I place greater emphasis on the role of "ideas"—non-materialistic aspect of institutions—in the shaping or adjusting of institutions. In fact, this notion of institutions, characterized by a complex of ideas, interests and institutional structure, is extremely useful in understanding Japan's "Institutional inertia," which it inherited from its past industrial success, and which now serves to constrain its institutional adjustment strategies (Thelen and Steinmo 1992; Spruyt 2000; Leander 2000).

In this view, "Japan was too successful in its efforts to catch up with the rest of the world" (Kumon 1999) in manufacturing sectors, such as steel, automobiles, consumer electronics, and hardware electronics. However, Japan's past industrial success itself can become an obstacle to further innovation and adaptation to a changed environment. From this perspective Japan is seen as having been locked into a pattern of *ideas* which were once congruent and resulted in successful innovation in manufacturing sectors, but which are no longer congruent under changed industrial circumstances. Therefore, Japanese *institutions*, which were most fit and efficient in manufacturing sectors of one age, are very likely to be unfit in a succeeding age characterized by novel patterns in technology and consumer demand. Established *interests*, however, predicated on past triumphs, resist rejecting the system that was responsible for their initial success. Manufacturing-oriented ideas, interests, and institutions underlying its once-successful industrial model are now characterized by "institutional inertia" in Japan, preventing the Japanese from adopting a flexible set of national institutions that could nurture new industrial sectors within the existing framework.

We are observing institutional inertia mostly in the "networked" Japanese firms that tend to be averse to risk and do not promote entrepreneurship within their ranks. Rather, they have been even greater barriers to newcomers' access to the domestic market, preventing the emergence of a new wave of entrepreneurial, PC-oriented companies. Indeed, Japan has almost no equivalent to the independent start-ups that have come to dominate many market segments in the United States. The same kinds of institutional inertia are also found in the Japanese policy tradition *per se* as well as other political economic institutions, which are the product of developmental ideas that have favored the interests of large firms that succeeded, for the most part, in their role as implementers of catch-up missions. Along with the Japanese industrial policy tradition in a narrower sense, typical examples include large firms-favored, catch-up-oriented economic policies and institutions, such as antimonopoly policy, intellectual property regimes, and capital market policy (Kim 2000, ch.5).

Japan's problems with institutional inertia are also involved in deeper aspects of the Japanese system of innovation.[8] Even if business strategies and government policies change, for example, Japan's institutional adjustment cannot be successful unless the underlying "science and technology (S&T) infrastructure,"[9] which provides the industry with human resources and technological knowledge, simultaneously changes. The Japanese S&T infrastructure, such as the educational system, the employment and training system, and university-industry linkages, has been institutionalized to produce human resources and technological knowledge serving the purpose of catch-up in manufacturing sectors. In fact, the S&T infrastructure had been very effective in supporting Japan's success in steel, automobiles, consumer electronics, and hardware electronics throughout the postwar period. By the 1980s, however, the same S&T infrastructure came to be seen a major obstacle that prevented Japan from adjusting to a new technological environment (Kim 2000, ch.6).

To summarize, the Japanese computer industry cannot restore its fortunes through institutional adjustment simply by relying on the existing pattern of corporate strategies, policy traditions and S&T infrastructure. These factors have coalesced into an institutional inertia that has served to prevent the Japanese from adjusting their "hardware institutions" to the rise of software technologies. In my theoretical view, the inability or unwillingness to change the out-of-date socioeconomic system lies at the heart of Japan's industrial failure in the computer architecture and software sector.

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[8] To conceptualize the deeper aspects of a social system relating to technological innovation, evolutionary economists adopt the concept of "national systems of innovation"—the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies (Nelson, ed. 1993; Lundvall 1992).

[9] According to Margaret Sharp, S&T infrastructure involves high quality secondary education, a good vocational training system, a strong university sector, a well-established academic research base with a major postgraduate component, university-industry linkage, research associations that support technology dissemination to small and medium-sized business, and the encouragement of regional initiatives bringing together firms, universities, and research institutions (Sharp 1997: 101).

10. CONCLUSION

I have analyzed why Japan has failed to meet the unique technological challenges facing it in the field of software electronics, why the renowned Japanese industrial model has been a dismal failure with respect to software electronics, and why the Japanese state has not been successful in adjusting to changes in the technological environment caused by the rise of software electronics. What makes my research most compelling is the fact that Japan's failure in software electronics is vividly contrasted with its success in the field of hardware electronics.

The Japanese industrial model did not fit the institutional requirements for efficient innovation in software electronics. For example, vertically integrated Japanese industrial organizations and developmental industrial policy were well suited for high-volume, capital-intensive hardware component production, in which manufacturing prowess was the key to success, and of which technological parameters were moderately predictable. However, the Japanese industrial model has not been effective in encouraging software electronics, which has unpredictable technological paths and requires less scale of economy, and in which trial-and-error research and breakthrough innovations are centrally important factors. As I have argued, this initial lack of fit between software electronics and Japanese sectoral governance structures in the computer industry goes a long way to explaining why Japan has been floundering in the computer architecture and software sector.

The question of central importance that has been raised here is whether or not, or to what extent, the Japanese can adjust their existing national institutions to the changing technological environment and embrace a new technological sector—software electronics—within the existing framework of Japanese "hardware institutions." It appears to be the case that Japan's efforts of institutional adjustment so far have not been sufficiently flexible to bring about the rise of "horizontal" governance structures in existing institutional settings. Instead, we are observing a form of institutional inertia inherited from Japan's industrial success in manufacturing sectors during the postwar catch-up period. Industrial structure, policy traditions and the S&T infrastructure in Japan, which were responsible for Japan's mammoth successes in the manufacturing sectors, are now regarded as the source of Japan's inflexibility, subsequently deterring the emergence of appropriate governance structures for fostering the development of software electronics.

The nature of Japan's problems in the PC industry lies in the low level of flexibility in the Japanese system, which impedes its ability to rearrange its national institutions in such a way as to be able to optimally cope with the rise of new technological systems. Of central importance has been the way in which the Japanese state has lacked the technological fitness to adjust to the transition from hardware-centered to software-centered paradigms that began in the late 1970s or early 1980s. A significant policy implication stemming from this research is the question of the extent to which Japan's further success or failure in the rapidly changing computer industry—which is now in the so-called network era (or the post-PC era)—will also depend on this kind of technological fitness.

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Sangbae Kim. Research Fellow. Korea Information Society Development Institute (KISDI), 1-1 Juam-dong, Kwachun, Kyunggi-do 427-710, Korea. Tel: +82-2-570-4090(O), Fax: +82-2-570-4249, E-mail: sangkim@kisdi.re.kr.