

Moderators of the Diffusion of
Technological Innovation:
Growth of the Japanese PC Industry

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Contents

PC's: Standards, Innovation and Diffusion.....	1
Positive Externalities and Switching Costs for Computer Architectures.....	1
Personal Computer Invention and Early Innovations.....	2
Global Diffusion of the PC Innovation.....	4
Competition Between Established and Startup Firms.....	5
Differences Between Nations in the Rate of Startup Success.....	6
Barriers to Entrepreneurship in Japan.....	7
Diffusion of PC Innovations in Japan.....	7
Role of Institutions in Nurturing the Japanese Computer Industry.....	8
Phase I: 8-bit era, 1975-1982.....	9
Phase II: Reign of NEC, 1983-1991.....	10
Phase III: DOS/V and Kurofune PC, 1992-present.....	11
A Model for Diffusion Moderators.....	12
Institutions as Barriers to Competition.....	13
Language Barriers.....	15
Multiplicity of Standards.....	16
Availability of Substitutes.....	17
When is a PC not a PC?.....	17
Assessment of the Model.....	19
Directions for Future Research.....	20
References.....	21
Figures and Tables.....	25
Table 1: Major PC Architectures.....	25
Table 2: Externalities and Switching Costs by Product Class.....	25
Table 3: Computer Technological Regimes.....	26
Table 4: Global PC production by country.....	27
Table 5: PC Sales by Established and Startup Companies.....	27
Table 6: PC Startup Companies Compared to Measures of Culture.....	28
Figure 1: Causal Model for Delayed PC Acceptance.....	28
Table 7: Support for links in causal model.....	29
Figure 2: Production of PC and WordPro units.....	29
Table 8: Game vs. Business Software in Japan.....	30
Figure 3: Recent PC sales in Japan by architecture.....	30

Technological innovation is always an “unusual event”, in that, as Schumpeter (1934) argued in his *Theory of Economic Development*, it disrupts the equilibrium or cyclical flow of the economy. Such new innovations he generally ascribed to new firms (Nelson 1992).

In past two decades, one of the most important such innovations was the personal computer. Little understood (at least in the English-speaking world) is that the diffusion patterns were very different in the two largest markets, the U.S. and Japan. Less understood still are the reasons why.

This pattern of technology diffusion in Japan is examined in response to two unusual events — the invention of the PC in 1975 and a new 1990 standard that facilitated competition by new entrants. The pattern is analyzed in terms of network externalities provided by computer standards, as well as possible cultural and institutional differences between the two nations. From this analysis, a causal model of diffusion moderators is proposed, which is examined in light of the available empirical data. Finally, the paper concludes with suggestions for further research on such moderators of innovation diffusion.

PC's: Standards, Innovation and Diffusion

The role of positive network externalities is a well understood part of the global diffusion of the personal computer innovation during the 1980's.

Positive Externalities and Switching Costs for Computer Architectures

Competition in computer systems is moderated by standards known as architectures (Morris & Ferguson 1993). For personal computers, these architectures are defined by the microprocessor, operating system software and particular configuration of the Read-Only Memory firmware such as the BIOS of the original IBM PC (Table 1). Upward-compatible supersets of these components can be used to extend an architecture, such as the switch from a Motorola 68030 to 68040 processor or the Windows 3.1 to Windows 95 system software.

(Insert Table 1 here)

Such architectures fit within theories of standards as a non-pure public good, voluntarily adopted, increasing competition between producers who adopt them and enabling new entrants by imitation (Antonelli 1994). A key benefit to standards is that they provide network externalities — non-exhaustible benefits to users of the standard — which for architectures includes the availability of products such as software, peripherals and expansion cards as well as services such as training and technical support. These improve the attractiveness of standardized products to customers, thus increasing growth rates for producers (Metcalf & Miles 1994).

Standards also tend to discourage switching to substitute products outside the standard, but facilitate switching within the standard (von Weizsäcker 1984). Finally, standards are often path-

dependent, in that they are distinguished by some arbitrary quirk of history rather than an inherent characteristic of the technology (David 1985).

In addition to architectures, buyers may choose other types of computer products involving standards (Table 2):

- Personal computers are products built to conform to an architecture standard; as such, the cost of switching between individual PC's (within the same standard) is low even if the cost of switching between architectures is high.
- Business software — such as word processors or spreadsheets — often has informal *de facto* standards for usage and positive externalities associated with training and add-on products; unlike PC's, the products are not often functionally equivalent, so switching costs exist in terms of document compatibility and user training.
- Games, unlike business software, are almost always used as stand-alone packages, and so have none of the switching costs associated with business software.

(Insert Table 2 here)

Personal Computer Invention and Early Innovations

The invention of the personal computer marked a change in the technological regime (to use the terminology of Nelson & Winter 1982: 259) of the computer industry. (Table 3). Because this change entailed three major shifts in the nature of computing — from institutional to individual *customers*, from limited-run to mass-market *production*, and from industrial to consumer *distribution* — PC advocates are not engaging in their usual hyperbole to term it a “revolution”.

(Insert Table 3 here)

The PC revolution was spawned by three related technological developments in the mid 1970's: the sequential invention of the microprocessor, the personal computer and the application software package. As each was commercialized as an innovation¹, it led to the next invention, and together they enabled the creation of an industry that now registers global sales in excess of \$100 billion.

Intel invented the first microprocessor (the 4004) in 1971, but its significant innovation was the first true 8-bit microprocessor, the 8080 in 1974.² The low-cost microprocessor changed the economics of computer production by becoming the first central processing unit (CPU) mass-produced in units of millions rather than hundreds or thousands. At the same time, the large

¹ We adopt the distinction between invention and innovation of Nelson & Winter (1982: 263-265)

² The historical discussion contained herein is intended to support the discussion of the Japanese PC industry; for a more comprehensive summary, see Langlois (1992).

market financed R&D such that a typical desktop computer of 1990 had more computing power than the top-end superminicomputer of 1980 or mainframe of 1970.

The Intel 8080 innovation enabled the invention of the personal computer, which is generally attributed to a small New Mexico start-up firm, MITS.³ The January 1975 *Popular Science* cover story on its Altair 8800 do-it-yourself kit inspired a hacker named William Gates III to drop out of Harvard to co-found Microsoft. On the other hand, the Altair was a kit computer oriented towards hobbyists. The Intel 8080 architecture evolved into a class of assembled personal computers — based on the Z-80 (a Zilog processor compatible with the Intel 8080) and the CP/M operating system, but small variations in the architecture between models made software development difficult.

Instead, the key innovation was the April 1977 release of the Apple II, which enabled the invention of the computer spreadsheet, Visicalc, announced in 1978 for the Apple II. Visicalc was the crucial innovation — the first important PC application software package — in that it provided a reason for non-hobbyists to buy a personal computer. The positive externalities of the available software became the key success factor for PC sales, as makers of innovative PC's lacking software soon found out.

Personal computers necessitated a key marketing innovation, the consumer distribution of computer products. The Apple and CP/M machines fathered a series of computer dealers and chain stores that later enabled distribution of the IBM PC and its clones. Meanwhile, Tandy established its PC's through use of its existing national dealer network.

The key standard for the industry was set by IBM's decision to build its personal computer using existing components, resulting in an open standard that did not exclude new entrants. Released in August 1981, IBM Personal Computer used a processor from Intel, an open architecture for expansion boards, and an operating system from Microsoft. This strategy allowed rival companies to build “clones” of IBM's product. In 1984, IBM was the first to introduce a computer based on Intel's faster 80286 processor, but was matched or beaten by “clone” makers in subsequent processors, as IBM attempted to regain control of the technology it created. Instead, IBM's share of the so-called “IBM compatible” market slipped from 100% in 1981 to less than 50% within a few years, until finally, in 1994, Compaq surpassed it as the leading Intel-based maker⁴.

³ Levering et al. (1984: 463) credits Japan's Sord with an April 1974 release of an Intel 8080-based microcomputer.

⁴ AnterAsian and Graham (1992) caution against an over-reliance on market share, but the positive externalities generated by share — or perceptions of share trend — appear to support the use of the construct in the case of computer standards.

With the authors of Visicalc otherwise distracted, it fell to a new firm called Lotus Development to develop the Lotus 1-2-3 spreadsheet for the IBM PC, which topped the best-seller lists by April 1983 (Levering et al. 1984: 132, 192). Meanwhile, startup firms WordPerfect and Ashton-Tate released word processing and database applications that, together with 1-2-3, provided the network externalities that fueled customer acceptance of the IBM PC.

The other important innovation was the January 1984 introduction of Apple's Macintosh, (incompatible with the IBM standard) which was the first to popularize the graphical user interface developed by Xerox Corp. Although Microsoft responded with its Windows add-on for MS-DOS in late 1985, Windows was not perfected until 1990, and Apple held a demonstrable ease-of-use advantage until 1995. Apple's introduction of its first laser printer in 1985 combined with its graphics capabilities to create the "desktop publishing" niche market. Despite such advantages, various marketing miscues and technology delays — coupled with the strong externalities accruing to the IBM standard — prevented Apple from increasing its worldwide market share above 10%.

Instead, the vast majority of the world's business computers (except in Japan) had coalesced by the late 1980's around PC's that ran identical MS-DOS and application software to those used by the IBM PC, a standard that created strong positive externalities for both hardware and software producers making complementary products (Langlois 1992).

Global Diffusion of the PC Innovation

Personal computers gradually diffused to developed countries that featured high per-capita incomes, level of education and technological sophistication, and the interaction of education and technological skill known as "computer literacy". The earliest such countries were those that developed their own computer industry, or had high levels of English fluency — to enable diffusion of PC products and technologies from the United States.

Enabled by its role as the inventor, its large domestic market and rapid diffusion of PC's, U.S.-owned firms have consistently held approximately a 50% market share. As more non-U.S. have succeeded in exporting to U.S. (or bought market share by buying failed U.S. start-ups), more U.S. firms, in turn have expanded operations abroad. Japanese firms have held about a 10% share — primarily for their domestic market, as have European firms in the aggregate, while the rest is split primarily among Canada, Korea and Taiwan (Table 4).

(Insert Table 4 here)

Such statistics measure the ownership of a brand name, not value-added. A given PC may include a processor from the U.S., memory from Korea, a hard disk from Singapore, a CD-ROM from Japan and a motherboard from Taiwan. There have been many debates over which technology provides the key differentiation or long-term strategic advantage, but the

comparatively small year-to-year variation (absent significant mistakes in execution) suggest that brand name, reputation, distribution — all determined by the marketing organization's strengths — are at least as important as the actual product content in market success.⁵

At the same time, a fairly consistent international division of labor has arisen, fueled by positive externalities of geographically localized industries within regions (such as Silicon Valley) or small countries (such as Taiwan). The U.S. produces microprocessors, operating systems and applications; Japan, semiconductors, floppy drives, CD-ROMs, LCD screens and laser printer engines; Taiwan, motherboards, expansion cards and assembled systems and Korea, semiconductor memories. Some technologies shifted from the U.S. to Asian countries in the 1980's, and a similar shift has occurred from Japan in the 1990's.

Competition Between Established and Startup Firms

There are many alternate explanations, but overall results suggest that established firms pursued similar strategies in each country, particularly among existing makers of larger computers. So the incompatible PC strategy of DEC in the U.S. (as told by Langlois 1992) is very similar to the incompatible PC strategy of Fujitsu in Japan. As noted by Flamm (1988: 227), existing firms have incentive to delay innovations. Many established firms, enjoying good reputations and distribution networks, sold high priced PC's that would support their expensive cost structures and the high profits they'd come to enjoy in large computer systems. Even IBM — whose invention of the IBM Personal Computer set the standard for most of the industry — failed in its attempts to re-differentiate its products when it realized its strategy was more successful for Microsoft and Intel than it was for IBM.

The difference between DEC and Fujitsu appears to be competition from entrepreneurial rivals in the U.S. (e.g., Compaq, Dell) which rendered DEC's strategy obsolete long before that of Fujitsu — which did not have to worry about start-up competitors until foreign firms like Compaq entered the market nearly a decade later. In fact, a re-analysis of Langlois's (1992) data suggests that the emergence of such start-up firms was confined to a few countries like the U.S. and Taiwan and did not include Japan.⁶ (Table 5).

(Insert Table 5 here)

⁵ Even allowing for this, these figures tend to understate the role of some countries, particularly Taiwan, which exports assembled systems on for distribution under U.S., European and Japanese brand names (Kraemer & Dedrick, forthcoming).

⁶ There are major limitations to this analysis, both in terms of the original data and the methodology of this paper's aggregation. A large percentage of the sales are not assigned to any specific company. The figures are distorting by reporting in total units across market segments, particularly in the early 1980's when \$100 home computers from Timex (US) and Sinclair (UK start-up) and \$200 home computers sold by Commodore (Canada) and Atari (US start-up) count the same as business systems priced at \$3-5,000. Also, this truncated sample shows only rates of company success, not company formation. Still, it reflects the most complete global time series published for this period.

Differences Between Nations in the Rate of Startup Success

Why are there such dramatic differences in the rate of startup success? Differences between nations this rate of company formation may be specific to the computer industry, or reflect more general national characteristics. Such national differences can include both distinctive cultural and institutional characteristics.

With regards to culture, several studies have attempted to tie differences in international rates of entrepreneurship to Hofstede's (1984) study of employees of IBM in 39 countries. Based on questionnaires gathered in 1971-74, he factor analyzed the responses to identify four distinct values: a power-distance index (PDI), individuality, masculinity and uncertainty avoidance (which we replace here for semantic convenience by an inverse "risk-taking" construct).

- Shane (1993), in a study of per capita trademark creation by firms from 33 countries as corrected for per capita income and industrial mix. found strong support for risk-taking being correlated to innovation, but fairly weak support for PDI and individualism,
- McGrath et al. (1992) surveyed 1,217 entrepreneurs and 1,206 non-entrepreneurial professionals in eight countries. They used discriminant analysis to separate the two groups, finding 25 variable significant. These corresponded to higher PDI, individualism, risk-taking, and masculinity for the entrepreneurs.
- Dubini (1988) surveyed 163 new businesses in six regions of Italy. Of his seven-factor solution, the first corresponded to Hofstede's individuality, the third to PDI and the sixth to masculinity. He then cluster analyzed the respondents into three groups, one of which had somewhat higher levels of individuality, and another that had much higher levels of masculinity.

For each country, Table 6 shows the number of start-up and established companies from Table 5, as well as the percentage of sales (1980-1991) by that country's firms that were made by startup firms. It compares these to the Hofstede's reported values for the countries.

(Insert Table 6 here)

The results can be inferred as consistent with the risk-taking/entrepreneurship link, but not with the hypothesized relationships for the other variables. Individuality — a common attribute attributed to entrepreneurs — has the expected relationship between the U.S. and Japan, but the average individuality for countries with start-up PC firms is dragged down by a lower score for Taiwan⁷.

⁷ As suggested by Dubini (1988), it may be a mistake to assume the motivations and patterns of company formation are the same for all entrepreneurs. It may be that risk-taking is a good predictor of company formation, while individuality predicts innovation; if so, this would be consistent with the development of the Taiwanese PC industry emphasizing imitation of existing innovations at lower costs.⁸ So, for example,

Barriers to Entrepreneurship in Japan

Japan is generally held to be a hostile environment for starting growth-oriented technology-based firms, at least as compared to the United States.⁸ As Masayoshi Son, a successful PC entrepreneur in Japan, put it:

In the United States, there is not the negative perception of the entrepreneur that there is in Japan. In general, it's harder to be an entrepreneur in Japan than in the United States. Japanese banks will not loan money to you because they are more conservative. And because of the culture, it's harder to attract the best employees. They like to work for the big companies or the government because Japan is a lifetime employment country. (Webber 1992: 101-102).

But culture is an inadequate explanation of the difference; economic institutions — particularly the *keiretsu* industrial groupings — play a major role. Lifetime employment, for example, reflects a conscious policy of large Japanese firms only since the early 1960's. Methé & Bracker (1994) found that Japanese entrepreneurs sought freedom and independence (like their U.S. counterparts), but often ended up being captive subcontractors to the *keiretsu*.

Other studies focus on the availability of capital. Regulation of initial public offerings mean that the average Japanese start-up firm is much older than the average U.S. firm at time of IPO; this discourages both entrepreneurs and potential early-stage investors, since the payout may be delayed 15 years away vs. five for the U.S. (Borton 1992; Callon 1994; Matsuda et al. 1994). Tax laws both discourage investment by informal investors (so-called “angels”) and also the accumulation of capital that makes such investment possible (Callon 1994).

Two booms in Japanese venture capital (1972-1974 and 1984-1986) were relatively short-lived (Borton 1992). A third boom started in 1994, as a reaction to the success of U.S. Internet and multimedia start-up firms; Japanese ministries, financial companies and trade associations have been studying the U.S. venture capital patterns in hopes of encouraging multimedia-related Japanese venture businesses. Some policy reforms — such as loosening IPO requirements — have been enacted, but it's too soon to say whether these changes will be permanent.

Diffusion of PC Innovations in Japan

The diffusion of personal computers in Japan followed a quite different pattern from both mainframe computers and the contemporaneous diffusion of PC's in the United States. Competition was low, prices were high and multiple standards developed. The pattern suggests that both culture and institutions played a role.

Eisenhardt and Forbes (1984) found high levels of technical entrepreneurship in the U.S., moderate in the U.K. and low in Japan, as measured on several dimensions.

Role of Institutions in Nurturing the Japanese Computer Industry

As part of Japan's spectacularly successful postwar economic development, the government — led by its Ministry of International Trade and Industry (MITI) — targeted several key industries for infant industry protection. Targeting the electronics industry targeting was authorized by the “Law Concerning Special Measures for the Promotion of Specified Electronic Industry” in 1957, revised in 1971 and 1978 (JIPDEC 1980). Policies used during the 1950's and 1960's included tariffs, import quotas, foreign exchange controls and restrictions on direct investment and production by foreign companies. MITI used these restrictions as leverage to negotiate licensing of foreign technology on favorable terms, while its absolute power to deny technology imports was used to prevent domestic firms from bidding against each other, keeping license fees low. Its unwitting partners in this technology transfer at nominal prices included foreign firms — notably U.S. firms whose licenses of color television technology meant short-term profits and long-term extinction — and also the U.S. government, which forced AT&T to license its inventions (such as the transistor) to all comers as part of domestic anti-trust policy (Mowery & Rosenberg 1993: 49).

From the 1950's onward, MITI also specifically targeted the computer industry, beginning with an aggressive import substitution policy that had shifted by the late 1970's to exporting globally competitive products.⁹ Some scholars (Flamm 1988; Ancho doguy 1989) have termed that development a combined government and industry effort to target the world's most successful computer company, IBM. Certainly government policies were an essential part of the development.

Government computer procurements — particularly by NTT — provided both profits and capital to firms before their products could compete on their own merits, as did the quasi-public Japan Electronic Computer Company, established in 1961 to use low-interest government loans to purchase mainframe computers from Japanese makers for rental by their customers. Finally, to help Japanese makers compete with IBM's mainframe computers, MITI and NTT spent ¥200 billion (ca. \$1 billion) from 1962-1980 on joint private R&D projects. The result was that from a 90% share of the Japanese computer market in 1958, IBM's share stayed below 50% after 1967 onward, relinquishing the top spot to Fujitsu in 1979, when both firms held about 23% share (Ancho doguy 1989).

The R&D projects also helped the semiconductor industry. One key technology targeted by both NTT and MITI in the period 1972-1981 was Very Large-Scale Integrated circuits that

⁹ The discussion of the computer industry development through the late 1980's is largely based on the work of Ancho doguy (1989), Okimoto (1989) and Fransman (1990); also covering this topic are Flamm (1988) and Mason (1992). The analysis of subsequent developments is based on various published sources, as well as interviews in Japan during 1994 and 1995.

formed the heart of mainframe computers. The VLSI R&D projects are generally considered to be the most successful of such government-sponsored R&D efforts: Japanese firms developed to world's leading production technology for many products, and their share of the world market nearly doubled to 51% from 1980-1988.

More recently, leadership has shifted from political to economic institutions.¹⁰ Certainly, economic institutions played a role in the development of the computer industry, particularly *keiretsu* industrial groupings, which provided semi-captive markets for producers and sources of patient capital for expansion.¹¹ Most would agree that the role of government policy has declined with the government's proportionate share in the economy with the growth of private firms. Some (e.g. Callon 1996) go so far as to argue that firms have grown so strong as to be immune to government influence, although this is not a majority view. Certainly more recent computer industry projects — primarily focusing on software technologies — have been far less successful than the VLSI project, having little or no immediate impact on Japan production.

Phase I: 8-bit era, 1975-1982

As in the U.S., the early sales of PC's in Japan were aimed at hobbyists. Takayoshi Shiina left a job selling DEC minicomputers to write Japanese software for the imported computers. He founded Sord in 1970, which released a series of PC's from 1974-1976 (Levering et al. 1984: 462-472).

Another entrepreneur to recognize the potential of personal computers was Kazuhiko Nishi, who dropped out of Waseda University to found ASCII magazine in 1977. In 1978, Nishi convinced Microsoft to appoint him exclusive Far East agent, licensing Microsoft's Basic interpreter to the many Japanese PC makers. ASCII later moved into distributing imported and domestic software, as did Softbank, a rival distribution and publishing firm founded in 1981 by Masayoshi Son.

The major Japanese electronics companies — including Toshiba and Hitachi — introduced kit-based computers in 1976-77. In 1978-79, NEC, Hitachi, and Sharp introduced 8-bit machines with built-in Basic programming language. All used cassette-based storage and held 16K, 32K or 64K of RAM; most were based on the Z-80 processors used by CP/M machines in the U.S. Still, through 1978 45% of the market remained the hobbyist market, with a like amount split between science, business and real-time data acquisition. (Horiguchi 1983: 8-15).

¹⁰ The turning point has been variously set from the early 1970's to the mid 1980's, but 1980 — the year between Fujitsu's rise to number one and the end of the VLSI project — seems a convenient milestone.

¹¹ On the former, "As of 1968, about half the computers in use by firms in the major industrial groups were made by their *keiretsu*-group computer firm." (Anchordoguy 1989: 33). On the latter, most often cited are the billions of yen NEC received from the Sumitomo group in the 1980's to expand production capacity, helping it become the world's leading producer of semiconductors.

The best selling 8-bit machine was the NEC PC8001, which sold 150,000 units. From 1980-1982, NEC held around 44% of the market, with 16% for Sharp and 12% for Fujitsu when it introduced its FM-8 in 1982. Meanwhile, Sord held about 6%, having moved up-market to emphasize more expensive machines with 128-1,024K configurations.(Horiguchi 1983: 30-31). On behalf of Microsoft, Nishi announced an 8-bit MSX standard in 1983 adopted by the less successful makers for home computers.

Many firms tried to export. Both Sharp and NEC exported their machines in limited numbers, with the NEC's portable — sold by Radio Shack as the Model 100 to countless journalists — the most popular. (Mannes & Andrews 1993: 209) More successful still was Seiko's Epson subsidiary, whose dot-matrix printers captured 70% of the Japanese market and became standard issue for both the Apple II and the new IBM PC. (Horiguchi 1983: 51). Low-end home machines by Commodore and Sinclair were imported, but IBM sought to sold a Japan-specific IBM 5500 computer rather than one based on the IBM PC sold in the U.S. and Europe.

Phase II: Reign of NEC, 1983-1991

If the IBM PC was the watershed for the personal computer in the United States, then the compatible development in Japan was NEC's PC-9801, released a year later in October 1982. Although it was not immediately obvious that NEC's machine would surpass other 16-bit offerings, NEC held several advantages. One was the chain of 180 retail microcomputer stores it built after disappointing sales through home appliance dealers. (Fukunaga 1988: 32).

Another was its courting of Japanese application software houses, by distributing detailed specifications in advance of the release. (Fukunaga 1988: 33). The effort was rewarded with the widest selection of application software. The most important of these was Ichitaro, a word processor that fully supported the Japanese language, which was released in August 1985 by JUST Systems, a company founded in 1981 to sell mid-range office computers.

Early estimates placed NEC's share of the 16-bit market at upwards of 80%, and its success was rewarded in 1987 with the first (and only) clone, from Seiko Epson, which also offered the first PC-98 compatible laptop (Fukunaga 1988: 33).¹²

The PC-98 was based on the same Microsoft/Intel architecture used in the IBM PC, but the MS-DOS operating system had to be extensively modified to support Japanese language processing.¹³ In addition to the translation needed for all non-English speaking countries, the

¹² NEC filed an injunction against Seiko, claiming copyright infringement (much as IBM did against several 2nd-tier clones in the U.S.), but Seiko modified the product to eliminate the infringement and the two parties settled out of court in November 1987.

¹³ Most of the earliest NEC computers used processors produced by NEC's semiconductor division, both licensed copies of the Intel 8086 and 8088 and a later NEC series. Intel sued NEC in the U.S. claiming copyright infringement, eventually losing in 1989, but NEC was unable to keep up with Intel's processor revisions and eventually switched to buying Intel processors for its own PC's.

operating system needed major revisions to support the so-called “2-byte” representation of Japanese characters, since the single 8-bit byte (containing values 0-255) was inadequate to store nearly 7,000 characters defined for the Japanese language. The computer also needed to be enhanced to contain screen representations of these characters (“fonts”), and also a Front-End-Processor (FEP) which consisted of an on-line dictionary to convert phonetically-spelled words into their character form.¹⁴

NEC’s competitors each developed their own, incompatible methods of supporting Japanese characters. The three most successful to do so using Intel chips and the MS-DOS operating system as a starting point were Fujitsu, IBM Japan and Toshiba. Apple also opened a subsidiary in Japan in 1983, and begun selling a *kanji* version of the Macintosh in 1986, and its first Japanese-capable laser printer in early 1989.

Other makers also set up subsidiaries in Japan. Lotus did so in 1985, shipping the first Japanese version of its 1-2-3 spreadsheet in 1986, which jumped to the top of the best-seller list, which it shared with Ichitaro for most of the next decade. Meanwhile, Bill Gates felt that ASCII president Nishi was no longer representing Microsoft’s interests in Japan, so when Nishi declined a position as a Microsoft employee, Microsoft ended its agreement with the “Bill Gates of Japan”¹⁵ to set up its own subsidiary in 1986 (Wallace & Erickson 1992: 330-333).

Phase III: DOS/V and Kurofune PC, 1992-present

Several attempts had been made by rival PC companies to dislodge NEC from its success. The most concerted came in 1987, when the so-called “AX” version of the PC/AT standard was proposed by 19 Japanese companies. However, each CPU was slightly incompatible, and the leading supporters (Sanyo, Sharp, Mitsubishi, Oki, Kyocera) of AX did not include any of the largest players in the PC market — Fujitsu, Toshiba, and IBM — which continued to sell their own incompatible clones (Fukunaga 1988: 33-34).¹⁶

The turning point came with IBM’s decision to reduce its costs by selling PC’s in Japan that were compatible with those it sold in the rest of the world.¹⁷ To do so, it moved all the Japanese processing from the computer’s read-only memory (ROM) to software that ran on an unmodified

¹⁴ The definitive discussion of the technical issues involved in computer representation of Japanese is given by Lunde (1993).

¹⁵ Like Gates, Nishi came from an affluent background dropped out of a prestigious private university to found his firm, and, according to Gates, is “more like me than probably anybody I’ve ever met” from Japan (Johnstone: 1993). Although the “Japan’s Gates” moniker was used frequently in the 1980’s for Nishi, recently it has been applied to Masayoshi Son, a Berkeley graduate who, born to a Korean-Japanese squatter’s camp, has since become Japan’s first computer (dollar) billionaire.

¹⁶ As one industry consultant put it, “Six companies with next to 0 market share united to create a standard with next to 0 market share. Is it any surprise AX failed?”

¹⁷ The following discussion of DOS/V and OADG is based on December 1994 interviews with Kikuchi Kentaroh of OADG, as well as other industry executives.

IBM PC. The result was DOS/V, which it announced and shipped with new PC's in October 1990. IBM offered to license DOS/V to competitors in hopes of increasing the architecture market share and thus available software; the result was the 1991 formation of the Open Architecture Development Group, which included IBM Japan, most of the minor MS-DOS makers, and Toshiba, which already sold IBM-compatible laptops in the U.S. and released its first DOS/V machine in 1991. This was extended by Microsoft's decision to release Windows 3.1 in May 1993 as a single version of Windows for all MS-DOS based systems: NEC, DOS/V and English-based DOS systems (Choy 1994: 5).

The end result of DOS/V was twofold. First, makers could sell the same machines as they sold worldwide, reducing their costs by using the components and configurations used for these global markets rather than special Japanese versions. Second, DOS/V removed barriers to new entrants (both in terms of technology and gaining compatible software), thus opening the market to new entrants from the U.S. (Compaq, DEC, Dell, Gateway 2000) and elsewhere (Acer, Olivetti).

The result was a crumbling of the high prices that had characterized the market since the beginning. A minor price skirmish came in Oct. 1990, when Apple and NEC sought to match prices of a smaller competitor. But the big salvo came with the Oct. 1992 decision of Compaq to sell PC's below the ¥200,000 mark (U.S. \$1,600), about half the price of existing products (Mori 1993; Choy 1994). The Compaq price salvo was dubbed by the Japanese press "kurofune PC", a reference to Commodore Perry's "black ship" invasion of 125 years earlier.

By 1994, both Fujitsu and Seiko Epson announced plans to offer DOS/V based systems, leaving only NEC and Apple outside the DOS/V camp. Apple, too, managed to increase sales during this period to become the second most popular manufacturer, so the sales growth of DOS/V systems came at the expense of NEC, Seiko Epson and proprietary DOS systems. In 1994, spurred by price cuts and a rising interest in multimedia and the Internet, sales jumped 30% despite a lingering recession. (Choy 1995).

A Model for Diffusion Moderators

Given the relatively affluent, technologically advanced and educated Japanese society, why have PC sales been comparatively delayed in Japan? Even though PC sales more than doubled from 1993 to 1995, far exceeding forecasts, Japan (with half the U.S. population) still buys as many PC's in one year as the U.S. does in one quarter.

Figure 1 shows a proposed causal model linking factors that delayed diffusion of PC in Japan. Here, the "delayed acceptance" construct is assumed to act as a moderator in the relationship between the creation of PC innovations and their purchase by Japanese industrial and

consumer buyers.¹⁸ The model is based on qualitative field research (primarily interviews) and a review of the English-language literature on the diffusion of personal computers in Japan; specific links made by earlier researchers are identified in Table 7.

(Insert Figure 1 here)

(Insert Table 7 here)

The model does not include the impact of Japanese government policies that target the computer industry, despite the importance of such policies in developing the mainframe computer industry. There are two reasons for this. First, the level of direct intervention by the government (notably MITI and NTT¹⁹) during this period and in this industry is much lower than earlier targeting efforts. Secondly, a presumed goal of such policies would be to increase domestic sales, exports and the competitiveness of Japanese makers, something that manifestly did not happen during the period 1975-1990.²⁰

Institutions as Barriers to Competition

Industrial Japan of the past century has been one of “managed competition”, in which government intervention was deemed necessary to prevent failures. MITI and other ministries sought to avoid problems caused by “excess competition”, and were most comfortable with a stable oligopolistic industry structure that included 5-10 firms (Murakami & Rohlen 1992: 95). As such, the policies and institutions (such as trade associations) specifically sought to discourage new entrants into targeted industries.

In addition to previously-mentioned barriers to new firm formation, two types of barriers serve to make it more difficult for companies (foreign or domestic) once established to enter existing markets.

The first is the well-known system of *keiretsu* cross-shareholdings, centered around bank, insurance and securities companies that provide financing for the other firms. Of the six major *keiretsu*, all have affiliated firms that make computers: Sumitomo (NEC), Dai-Ichi Kangyo Bank (Fujitsu), Mitsui (Toshiba) Fuyo (Oki), Sanwa (Sharp), Mitsubishi (Mitsubishi); in addition, Hitachi has ties to several groups (Miyashita & Russell 1994). These groups have a tendency to buy from sister companies — or at least not buy from competing groups.²¹ So in the 1960’s, groups unwilling to buy computers from competing Japanese groups were advised by MITI to

¹⁸ More precisely, the construct acts as a suppresser of the relationship (Bagozzi 1980: 72), since the magnitude of the effect (sales) is reduced as the value of the moderator (delayed acceptance) increases.

¹⁹ Although some of its shares were sold to the public in 1986-1988, as of this writing two-thirds are still held by the Japanese Ministry of Finance and NTT remains, at-best, a quasi-private corporation.

²⁰ Anecdotal evidence suggests that the Ministry of Education practiced a form of import substitution, by flatly prohibiting imported computers (notably those of Apple) from K-12 public schools.

²¹ Fixing the exact amount of such intra-group purchases has become intensely controversial because of the U.S. decision to target *keiretsu* as a non-tariff trade barrier in the 1980’s, so precise figures are hard to come by.

make their own rather than purchase imports (Anchordoguy 1989: 32-33), while, in the 1990's, at least one Japanese firm chose to buy an import rather than buy from a competing group or use its own group's inferior products.²² Sales based on *keiretsu* loyalties rather than product quality allowed less successful PC vendors to maintain at least some market share, delaying the consolidation of the various incompatible standards.

The type of barrier is the Japanese distribution system, in which major manufacturers provide financing and other support to large chains of (highly-dependent) exclusive distribution agents²³. Most major Japanese consumer electronics firms have such systems: Miyashita & Russell (1994: 142-151 and Choy (1994) list this as the single most important factor in NEC's PC success.

These barriers to entry are not absolute. In PC's, Seiko (a group of family-owned businesses that includes the well-known watch brand) was able to gain a significant share of the Japanese PC market despite its lack of prior experience manufacturing computers. Sharp was somewhat less successful, but has used its LCD screen manufacturing to produce notebook computers and also win a majority of the handheld "Personal Digital Assistant" domestic market.

Also, it must be noted that the leading PC-maker (NEC) was not the leading maker of earlier generation computers (Fujitsu), although it was the most successful beneficiary of government semiconductor R&D efforts associated with mainframe computers. It is notable that both companies entered the market before 1980, and both are multibillion dollar makers of consumer goods.

These systems of various economic institutions are not unique to Japan. Korea's *chaebol* are patterned after the *keiretsu*, and similar (though less effective) business groups can be found throughout Latin America. The groupings are different in degree, but not in spirit, to many combinations in Europe.

Instead, it appears that the U.S., Taiwan and the U.K. were unusual in spawning new firms to take advantage of the PC revolution. Even the rare Japanese start-up — Sord, the earliest PC firm — did not survive NEC's PC-98 standard and was bought by Toshiba in 1985.

Language Barriers

The computerized representation of the Japanese language is a complex problem, and one not unique to personal computers. Some data processing has been done using phonetic alphabets — either *romaji* (the Roman alphabet) or the *kana* (two Japanese alphabets) — but a natural representation of Japanese requires support for *kanji*, the Chinese-based characters.

²² Interview with John Stern, American Electronic Association Tokyo office, Sept. 1, 1994.

²³ Kitchell (1995) argues that such systems have their origins in the political control of merchants and cottage industries during the Tokugawa era (1600-1868).

Several standards have been developed by the Japan Institute for Standards (JIS) for representing Japanese on computers. The 1983 standard includes a) the 1,945 Kanji that every Japanese student learns before high school graduation b) approximately 4,000 additional *kanji*, and c) various other Japanese and Western alphabets to total approximately 6,000 characters. To represent these characters defined by the NEC, Hitachi, NTT each developed an encoding system, as did IBM, Apple, DEC, Data General; Fujitsu had two, one for mainframes and minis, one for PC's. In addition to the standard characters, each set contains 0-5,000 supplemental characters, plus room for another 300-5,000 characters defined by the user (Lunde 1993: 295-324).

This meant that complete screen display on Japanese PC's required more data to store the 6,000 characters in Japanese, instead of the 95 (or 223) printable characters needed in Europe and the Americas. In addition, each character was more complex, increasing the amount of data that needed to be stored in ROM, on a hard disk, and transferred to the screen. These increased performance requirements meant that it was only with the release of processors in the class of the Intel 386 (1987) and Intel 486 processors (1990) that performance for ordinary word-processing became acceptable.

Of course, as noted earlier, these capabilities served as a barrier to new entrants, since a Japanese operating system (or CPU ROM) needed to include front-end processor software, fonts, and the FEP dictionary of pronunciations. Because U.S. operating systems and applications did not support two-byte fonts, it also meant developing additional software interfaces and convincing local software authors to support your architecture. This effectively prevented the sale of off-the-shelf "PC clones" in Japan, except to those willing to limit themselves to Western languages in exchange for a lower price.

Finally, the complexity of the Japanese language prevented the diffusion of mechanical and electro-mechanical typewriters for all but the most specialized of applications. This meant that individuals and businesses did not own typewriters and children did not learn typing in their school or home, until the advent of the *wordpro* electronic typewriter and PC in the mid-70's. Still today, many Japanese adults — including most males born before 1960 — do not have the basic keyboard skills necessary to use a computer.

Multiplicity of Standards

The successful sale of personal computers has required the positive network externalities associated with packaged software.²⁴ The causal relationship between software and market share

²⁴ Although custom software is more common for workstations, minicomputers and mainframes than for PC's, packaged software has gradually become more important for these types of computers since 1980. The comparatively limited availability of package software for UNIX-based workstations has also prevented several attempts to distribute them through retail channels as high-performance personal computers.

is confounded like the chicken and the egg: a more popular architecture will have more software packages, while more software packages will make an architecture more popular. These feedback mechanisms generally snowball to encourage standardization on a single architecture within a given segment of the computer industry: IBM 360 in mainframes, DEC VAX-11 in minicomputers, UNIX in workstations, and Windows in PC's.²⁵

But the Japanese market settled into a system of multiple standards in the personal computer market: NEC, Fujitsu (FMR and FM Towns), IBM Japan, Toshiba and later Apple.

NEC (and the Seiko clones) holding the overwhelming majority of PC sales using its modified version of the MS-DOS operating system. Imported (primarily U.S.) software was successful in cases where it could be effectively translated, while Japanese makers did best in those cases where the differences in language (e.g. with word processors) or institutions (e.g., accounting software) were too great for a simple translation to be adequate. The incompatibility of the NEC with the IBM standard meant that foreign applications had to be extensively modified, while PC's produced for the Japanese market were not compatible with the rest of the world.

At the same time, NEC's decision not to license its architecture (and its legal threats against Seiko) meant that other firms had to strike out on their own, which they did. Fujitsu, as the largest mainframe vendor, could also sell heavily to its installed base of customers. Despite never attracting more than 12% of the Japanese market or 3% of the world market, it managed to maintain one (later two) unique standard(s) until, three years after the introduction of DOS/V, it announced its third, the FM/V.

Toshiba and IBM supported their engineering efforts through sales of PC's elsewhere in the world (primarily the U.S. and Europe), but had to modify their systems for use in Japan. Smaller firms attempted to build critical mass (such as with AX) but failed. Finally, the failure of Microsoft to support the Japanese language (as Apple did) in its operating system meant that other foreign PC firms had to develop their own Japanese language support.

Cottrell (1994) argues that these fragmented standards were the key reason why Japan failed to develop a globally competitive PC package software industry. Japanese firms were spread between multiple platforms and no one platform could deliver more than 50% of the Japanese market — which in turn was no more than 5% of the global marketplace, smaller even than Apple's 9%, long perceived as fatally small. This resulted in less software in Japan, which in turn slowed market development (and thus limited software growth).

²⁵ Apple has successfully maintained standards (the Apple II and later the Macintosh) by segmenting the market and targeting specific market segments — notably K-12 education, universities, desktop publishing — as well as by differentiating itself through ease of use. One way is through careful cultivation of software developers, a loyalty that has thus far enabled to resist (though not defeat) standardization pressures.

Availability of Substitutes

One key factor delaying the acceptance of personal computers was the development and refinement of substitute products, both at higher and lower prices than the PC's.

For businesses, one alternative was the *ofucon*, the office automation minicomputers. Sales of office automation minicomputers continued to increase until 1991, when the economy slipped from "bubble" growth into a recession (JIPDEC 1994: 42). Aided by faster processors and lower prices, PC sales recovered in 1993, but *ofucon* sales are continuing to decline.

The other substitute product used by business and individuals was the *wordpro* word processor, which eventually filled the role that typewriters had served for 100 years in Western countries. *Wordpro* sales registered explosive growth from 1985 onward, when the introduction of the personal word processor reduced the average price in one year from ¥140,000 to ¥40,000, with total word processor production exploding ten-fold from 1984 to 1987, surpassing corresponding PC figures until 1993, as shown in Figure 2.²⁶

(Insert Figure 2 here)

Finally, at the low end, various types of home and game computers served as PC substitutes for many consumers. These included the 8-bit MSX architecture used by consumer electronics companies, as well as a series of Japan-developed dedicated cartridge game consoles beginning with Nintendo's Famicom in 1983.

When is a PC not a PC?

The MSX machines have been counted in Japan as personal computers, but various game players from Nintendo and Sega have not. From a technology and marketing standpoint, the distinction is somewhat arbitrary, which leads to the key dilemma: why were their development paths so different?

Both game machines and PC's had microprocessors, RAM, video output and mass storage. The Sega Genesis uses the same 68000 as the original Macintosh, while the more recent Sony PlayStation uses a RISC processor used in Silicon Graphics workstations until 1993 (Battelle and Johnstone 1993; Okasan Securities 1994). Nintendo's purchases added \$1 billion annually to the sales of Japanese semiconductor firms, led by Ricoh (Scheff 1993: 32).

The technology of business and game software is also similar. Video games (PC or cartridge) requires the graphics of a drawing program, the data structures of database and the reliability of a word processor; in some areas (such as speed and the use of low-level programming techniques), the requirements are often more stringent than for business packages.

²⁶ Domestic sales for word processors are not directly reported, but production generally corresponded to domestic use until the mid-1990's, when Japanese firms began moving production to Asian lower-cost countries.

The marketing distinction between game and business is also becoming an increasingly tenuous one, given that the broad class of consumer-oriented software — particularly multimedia titles involving entertainment and “edutainment” — is seen by leading U.S. software makers as the larger growth opportunity than the traditional business productivity applications²⁷. The separation of PC games from video cartridge games — while more frequently made — is also somewhat arbitrary, given that the most popular titles usually appear on both formats, and they share overlapping distribution channels; as both game machines and PC’s shift to CD-ROM distribution, even the delivery medium is becoming similar.²⁸

Japanese software developers — many of them small start-ups, as with their U.S. counterparts have done quite well in package software development. If the packages are defined as being business applications, or system software (operating systems and utilities), then Japan imports a considerable amount from the U.S. and exports little in return. If, however, software includes video game cartridges (and more recently, CD-ROMs), Japan imports very little from the U.S. and exports a great deal. So, for example, in 1993, Japan’s ratio of imports to exports was 20:1 for so-called “basic” software, but 15:1 in favor of exports for game software(See Table 8). It would appear that any attempt of American triumphalism (or Japanese defeatism) over perceived American dominance in software finds that supremacy hangs on a thin definitional thread: what type of packaged software is involved.²⁹

(Insert Table 8 here)

The Japanese success in game software is actually less dramatic than the success by Japanese firms in game machines. The home video game console was invented in the United States in 1972 by Atari, but today all four of the most popular game console makers are Japanese firms (Nintendo, Sega, Sony, Matsushita) and three of the four use architectures designed in Japan.³⁰

The distinction between video game consoles and PC’s is greater than that for software, but there are many similarities. The Japanese names Nintendo’s Famicom (1983) and Super Famicom (1990) reflects their marketing as a family computers, and promises were made (but largely unrealized) that these would assume many home computer functions.³¹ As personal computers

²⁷ For an field study of a key multimedia product development effort and its role in Microsoft’s consumer strategies, see Moorthy (1995).

²⁸ Both formats are now shifting towards online electronic delivery, with PC games (“Doom”) being distributed via the Internet while Sega has begun distribution via its own cable TV channel (Battelle & Johnstone 1993: 120).

²⁹ Cottrell (1994) quotes Microsoft chairman Gates as saying “The software business is very American”, while Carmel (1995) writes about an American “culture of software.”

³⁰ The Matsushita (Panasonic) system uses an architecture designed by 3DO, a Silicon Valley startup firm.

³¹ In the U.S., similar units are sold as the Nintendo Entertainment System (NES) and Super NES. In both countries, the hyping of PC capabilities for Nintendo and Sega machines paralleled the failed attempts of Commodore and Atari in the early 1980’s to offer similarly-priced PC systems, connected to a television, that had both entertainment and household management capabilities.

start to shift into consumer distribution channels, and efforts continue to lower their price (while raising the capabilities of the game consoles), again the distinctions between PC's and game machines are becoming blurred.

In fact, it is more difficult to explain why companies that previously made playing cards (Nintendo) and pinball machines (Sega) came to dominate the world's video game market, rather than one of the major classes of PC makers, such as established Japanese consumer electronics firms or U.S. start-ups. Even if one sets aside firms committed to PC strategies (NEC, Apple) that included selling to the home, this does not include firms that were not burdened by such success (Sony, Atari) and thus, like Nintendo and Sega, could focus on the game market.

As with PC's, software plays a role as the key network externality for the success of a video game architecture; in fact, the link is stronger. For PC's, many home and business customers can be satisfied with buying a few key applications and then using them unchanged; but for video systems, the game soon becomes dull thus is, in effect, a consumable.³² And as with PC's, the most popular architecture attracted the most software.

Detailed analysis of different pattern between PC and game system industry development is beyond the scope of this paper; it may nothing more than a path dependence like the QWERTY typewriter (David 1985). But the success of any theory on technology factor endowment of Japan in the 1990's must successfully navigate this Scylla and Charybdis.

Assessment of the Model

The introduction of DOS/V in 1990 provides an external event that can be used as the basis of a quasi-experiment, a one-group pretest-posttest design in the taxonomy of Cook & Campbell (1979: 99), that can help us draw some inferences about the model's validity.

As discussed earlier, DOS/V has reduced the number of important standards to three: NEC PC-98, DOS/V and Apple's Macintosh. More importantly, it has enabled the entry into the Japanese market of makers of IBM PC clones. As a consequence, the number of competitors has increased, while prices have decreased and sales have increased. As shown in Figure 3, the PC-98 sales have been almost flat in absolute terms while its market share has declined, trends that appear to be continuing.³³

(Insert Figure 3 here)

³² Unlike PC's and the original Atari game consoles, Nintendo established a business model where it tries to control the manufacturing and licensing of all games for its consoles, allowing it to sell the "razor" at a loss and then reap the profits from the "razor blades." Despite threatened anti-trust action, this strategy has been emulated to a greater or lesser degree by Nintendo's successors.

³³ The figure is not meant to take the place of conventional tests of statistical validity, but realistically the threats to construct validity (to use the terminology of Cook & Campbell 1979) require more attention than any possible threat to statistical validity.

The problem — as with most such quasi-experiments — is that the lack of random selection makes it impossible to completely rule out confounds. Other factors may explain the reduction in prices, while increased popularity may have also been due to performance increases that followed “Moore’s law”,³⁴ or unmeasured but possibly changed levels of user skills. Also, nothing related to the DOS/V external event would explain why Apple’s sales have *increased*, either in absolute terms or in terms of market share. Clearly, further research is necessary (as proposed later) to provide more rigorous test of the model’s causal links.

Directions for Future Research

Although many confounds in the diffusion pattern of PC’s in Japan may defy disentanglement, such as the apparently unique pattern of persistent incompatible architecture standards. However, some aspects of the model do lend themselves readily to empirically research.

First, in terms of barriers to entrepreneurship, the missing mediator in the (negligible) level of PC startup company success in Japan is rate of company formation. Were new companies formed at the same rate as in other countries, such as the U.S., U.K. or Taiwan? If so, why were they not more successful? The government’s recent and proposed policy changes towards venture businesses could offer a quasi-experiment that sheds light on the role of government policy (particularly involving capital formation) plays on the rate of company formation in the computer industry.

Since they are temporally confounded, it is difficult to quantify the respective contribution of lower prices and increased performance, but a lab experiment in consumer preferences using hypothetical configurations would improve our understanding in this area. Experiments or surveys could also be used to establish how well an individual’s user skills (specifically keyboard proficiency) predicted their likelihood of using or buying a computer, particularly if self-reported temporal data (e.g., when did you first use a PC?) could be used to infer the direction of causality.

Other linkages do not lend readily lend themselves to micro-level validation, but instead need to be approached using macroeconomic data. Examples include the languageØcompetition and competitionØprices links, links which were supported by the effect of the DOS/V solution to the language technological issues.

The remaining links could be studied using econometric regressions for 1980-1995 with country as the sampling unit, with per capita PC use as the dependent variable. The first model would use a base model with independent demographic variables of income, education and

³⁴ A rule of thumb proposed in 1964 by Gordon Moore — later co-founder of Intel — which states that computing performance doubles every two years for equivalent cost (Rogers & Larsen 1984: 96-98).

technology, and then test for significant differences of extended models that include the following independent (or mediator) variables:

- Dummy variable (0,1) for kanji-based language countries (to show language acceptance)
- number of major competitors (competition acceptance).
- price in proportion to world market (for competition price and price acceptance)

Ideally, the second group of models would look at East Asian countries that require front-end processors for language support (e.g. Japan, Taiwan, Korea, China) the base model could be extended with a moderator of the personal word processors (measuring substitutes acceptance).³⁵ Also for these countries, the availability of language-processing technology could be tested as a predictor for the number of competitors.

Finally, linkages involving the co-existence of multiple standards have face validity among subjects, but are difficult to establish using either experimental or historical data: the best hope of validating these links is provided by computer simulation.

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³⁵ However, even counting these four countries and Hong Kong, it is questionable whether the number of countries would provide enough degrees of freedom in the observations to explain the results while ruling out possible confounds.

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Figures and Tables

Table 1: Major PC Architectures

<u>Architecture</u>	<u>Processor Standard</u>	<u>Computer Standard</u>	<u>Operating System</u>	<u>Approx. Global Market Share</u>
MS-DOS	Intel-compatible	IBM clone	MS-DOS	÷
“Wintel”	Intel-compatible	IBM clone	MS-DOS+Windows, Windows 95	70% ”
NT	Intel-compatible	IBM clone	Windows NT	< 5%
DOS/V*	Intel-compatible	IBM clone	DOS/V + Windows	4%
OS/2†	Intel-compatible	IBM clone	OS/2	< 5%
PC-98*	Intel-compatible	NEC clone	MS-DOS + Windows	5%
Other†	Intel-compatible	(various)	(various)	≈5%
Macintosh†	Motorola	Mac clone	Mac OS	9%

* Architecture for Japan market only

† Includes Japanese-compatible architectures

Table 1: Major PC architectures of the 1990's

Table 2: Externalities and Switching Costs by Product Class

	<u>Architecture</u>	<u>PC</u>	<u>Business Software</u>	<u>Games</u>
Differentiation	Medium	Medium	High	High
Switching Cost	High	Low	High	None
Positive Externalities	High		Medium	Low
Competitive Advantage	Market Size Applications	Time to Market Quality	Features	Novelty

Table 2: Strategic factors for PC products

Table 3: Computer Technological Regimes

	<u>Mainframe</u>	<u>Minicomputer</u>	<u>Personal Computer</u>
Invention	ENIAC (1945)	DEC PDP-1 (1960)	Altair 8800 (1975)
Key Innovation	UNIVAC (1951)	SDS 940 (1966)	Apple II (1977)
Key Standard	IBM 360 (1964)	DEC PDP-11 (1970)	IBM PC (1981)
Ascendant Period	1960's	1970's	1980's
Programming Language	Cobol	Fortran	C
Software	Custom	Custom	Package
Sharing	Sequential jobs	Time-sharing	n.a.
Market	Large firms; Government agencies	Large, medium-sized organizations	Organizations of all size; Individuals
Purchasing Level	Company	Department	User
Distribution	Direct sales	Direct sales Value-Added Reseller	Retail Mail order
Pricing	Per second of use	Per month	Purchase
Leading Makers	IBM and the "BUNCH" [†]	DEC, HP, Data General	IBM, Apple, Compaq, NEC
Maker Companies Formed	CDC (1959), Amdahl (1970)	DEC (1957), Data General (1968), Prime (1972) ^{††}	Apple (1976), Multitech (1976) [§] , Compaq (1982), PCs Limited (1984) ^{§§} , Packard Bell (1986)
Spin-off Innovations	Disk drives Operating systems Internet	Timesharing UNIX Graphics displays	Packaged software CD-ROMs
Regional Beneficiary	Twin Cities	Route 128	Silicon Valley Taiwan

[†] The "BUNCH" consisted of Burroughs and Univac (since 1986, merged as Unisys), NCR (since 1991, ATT GIS), Control Data Corp. (since 1992, Control Data Systems) and Honeywell (sold to Bull in 1991).

^{††} Since 1992, Computervision

[§] Since 1987, Acer

^{§§} Now Dell

Table 3: Comparison of technological regimes in the computer industry

Table 4: Global PC production by country

Region	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
U.S.	46.4	38.4	45.5	42.7	40.3	44.3	39.9	45.6	42.9	41.6	39.6	37.9
Canada	13.0	12.8	18.4	23.9	19.4	13.2	11.4	9.7	8.5	8.1	7.1	8.3
Europe	14.8	24.1	15.1	10.3	14.7	12.3	11.1	10.9	7.3	6.2	6.3	5.4
Japan	10.3	12.4	11.5	8.7	9.0	11.7	14.1	11.3	10.9	13.0	14.0	10.7
Taiwan								0.9	2.0	1.6	2.0	2.4
Korea								0.2	0.8	0.8	2.6	2.6
Unitemized	15.5	12.3	9.6	14.3	16.6	18.5	23.4	21.5	27.8	28.9	28.5	32.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Calculated from Langlois (1992), based on Dataquest data

Note: Figures shown are % of total units sold in that year.

*Table 4: Global PC production by manufacturers' home country, 1980-1991***Table 5: PC Sales by Established and Startup Companies**

Country	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
<i>Start-up companies</i>												
U.S.	18.4	19.0	15.6	15.5	16.4	13.5	15.6	20.6	21.4	21.0	20.9	22.2
UK	14.7	23.9	14.5	9.5	13.2	10.3	8.4	8.3	4.2	2.7	1.3	1.0
Taiwan								0.9	2.0	1.6	2.0	2.4
	33.1	42.9	30.1	25.0	29.6	23.9	24.1	29.8	27.5	25.3	24.2	25.6
<i>Established companies</i>												
U.S.	28.0	19.5	29.9	27.2	23.9	30.8	24.3	24.9	21.5	20.6	18.7	15.7
Canada	13.0	12.8	18.4	23.9	19.4	13.2	11.4	9.7	8.5	8.1	7.1	8.3
Japan	10.3	12.4	11.5	8.7	9.0	11.7	14.1	11.3	10.9	13.0	14.0	10.7
Korea								0.2	0.8	0.8	2.6	2.6
UK					0.4	0.5	0.8	0.1	0.2	0.1	0.2	
Europe (other)	0.1	0.2	0.6	0.7	1.2	1.4	1.9	2.5	3.0	3.3	4.8	4.4
	51.4	44.8	61.1	61.7	54.1	58.0	53.0	49.3	45.4	46.4	47.8	42.0
Total known	84.5	87.7	90.4	85.7	83.4	81.5	76.6	78.6	72.3	71.1	71.5	67.3
Unitemized	15.5	12.3	9.6	14.3	16.6	18.5	23.4	21.0	26.7	27.9	28.0	31.9
<i>% startups†</i>												
World	39.2	48.9	33.3	29.2	35.5	29.3	31.4	38.0	38.1	35.6	33.9	38.1
U.S.	39.7	49.4	34.2	36.3	40.7	30.5	39.2	45.3	49.8	50.6	52.7	58.6
U.K.	100.0	100.0	100.0	99.7	97.3	95.4	91.3	98.6	96.6	95.8	86.8	100.0
Taiwan								100.0	100.0	100.0	100.0	100.0

Source: Same as Table 4

Note: "start-up" defined as companies founded in 1972 or later. Sales of acquired companies assigned to parent company in first full year after acquisition.

† Ratio of (startup for region) / (total known for region)

Table 5: Global PC sales, 1980-1991 for established and start-up companies

Table 6: PC Startup Companies Compared to Measures of Culture

Country	PC Industry Firms 1980-1991			Culture Measures			
	Number of Firms		% sales	Hofstede's Indices			
	Startup	Existing	Startup	Individ.	Risk	Mascul.	PDI
Taiwan	2	0	100%	17	47	38	58
UK	3	1	97%	89	77	66	35
U.S.	16	13	44%	91	84	62	40
Canada		1	0%	80	65	53	39
Japan		8	0%	46	8	87	54
Korea		3	0%				
Italy		1	0%	76	62	72	50
France		1	0%	71	47	41	68
Total	21	28	36%				
Mean entrepreneurial countries				65.7	69.3	55.3	44.3
Mean non-entrepreneurial countries				68.3	45.5	63.3	52.8

Source: Table 5; Hofstede (1984)

† Masculinity corrected for proportion of females in the population sample, and Uncertainty Avoidance as corrected for age, s presented by Hofstede (1984). Values shown for Risk-taking is calculated as 120-(Uncertainty Avoidance) to invert the ordering of scores ranging from 8-112 on Uncertainty Avoidance since low uncertainty avoidance is associated with entrepreneurship.

Table 6: PC sales for startup firms vs. hypothesized entrepreneurial measures of culture

Figure 1: Causal Model for Delayed PC Acceptance

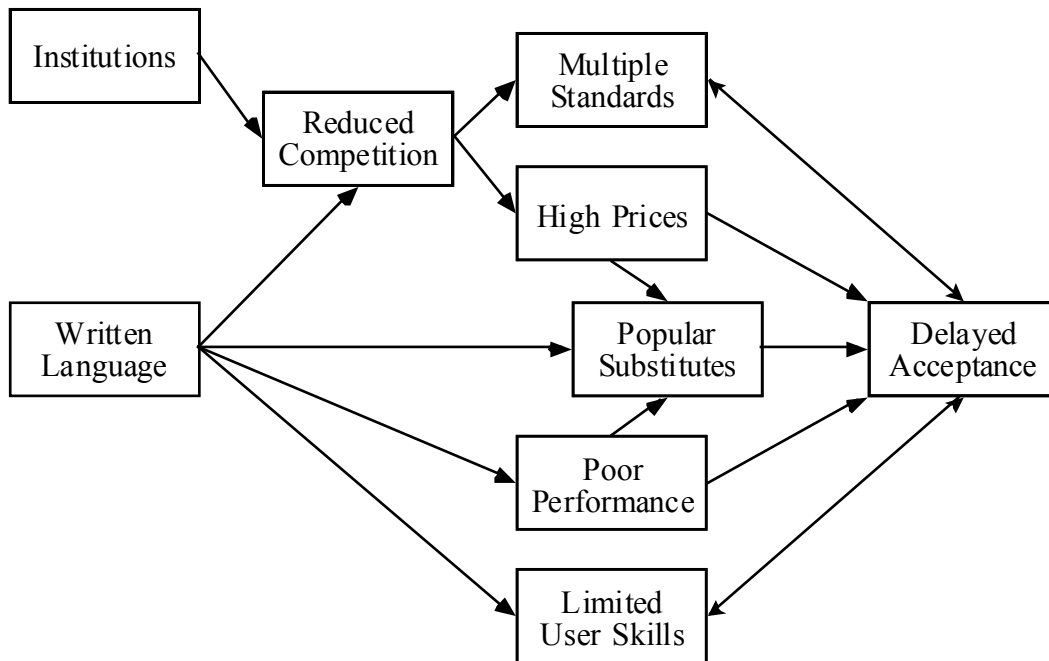


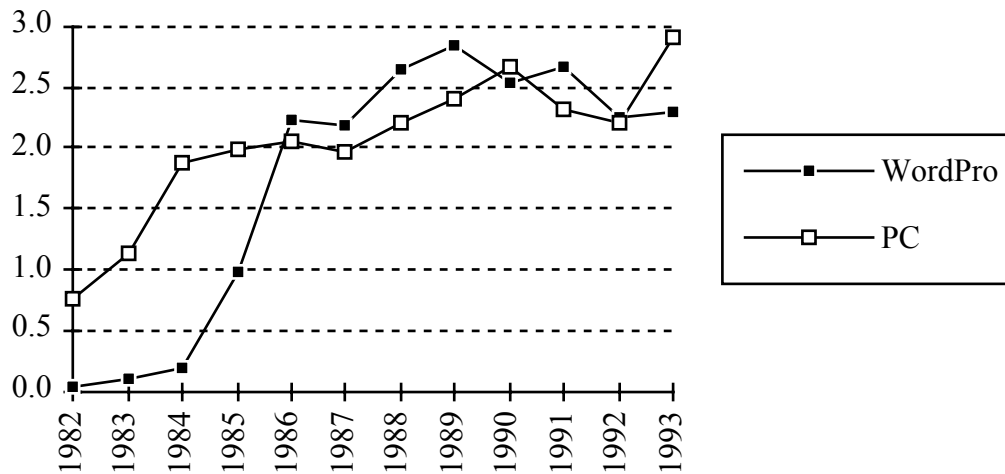
Figure 1: Causal model for delayed diffusion of PC's in Japan

Table 7: Support for links in causal model

IV [... Mediators ...]	DV	Source
Institutions	Competition ... Acceptance	Callon (1994)
Language	Competition Standards Acceptance	Cottrell (1994), Choy (1994)
Acceptance	Standards	Cottrell (1994)
Language	Competition Price Acceptance	Choy (1994)
Price	Substitutes	Choy (1994)
Language	Performance Acceptance	Choy (1994)
Language	Substitutes Acceptance	Choy (1994)
Language	Skills Acceptance	Choy (1994)

Table 7: Support for links in causal model from prior Japan PC research

Figure 2: Production of PC and WordPro units



Source: Yano Research (1985, 1987, 1989, 1995)

Figure 2: Japanese production of PC and WordPro units

Table 8: Game vs. Business Software in Japan

	Exports			
	Total	System	Application	Game
U.S.	¥106.5	¥8.7	¥1.1	¥96.7
Europe	¥42.8	¥0.8	¥0.3	¥41.8
Other	¥58.5	¥1.2	¥1.3	¥56.0
Total	¥207.9	¥10.7	¥2.6	¥194.5

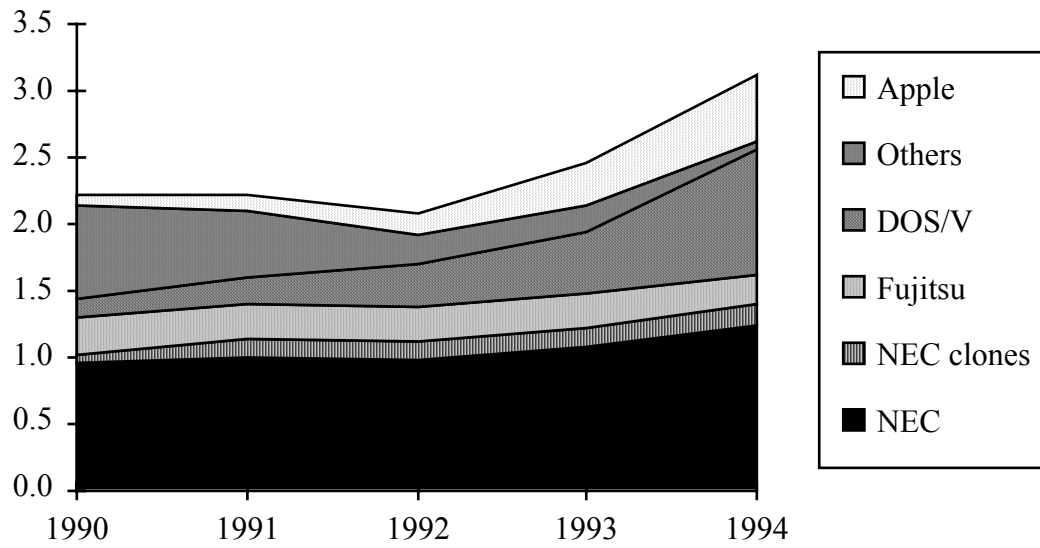
	Imports			
	Total	System	Application	Game
U.S.	¥243.1	¥182.7	¥54.3	¥6.1
Europe	¥5.2	¥2.1	¥1.0	¥2.0
Other	¥7.7	¥5.5	¥1.3	¥0.9
Total	¥255.9	¥190.3	¥56.7	¥9.0

1993 imports and exports, in billions of yen

Source: JEIDA (1995)

Table 8: Japan's balance of payments in packaged software, 1993

Figure 3: Recent PC sales in Japan by architecture



Source: Yano Research (1994, 1995); Choy (1995)

Figure 3: Recent PC sales in Japan by architecture