Is the Adoption of a Technology Efficient?

——Path-dependent Character of the Competition between Technologies——

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I. Introduction

The competition between technologies is characterized by the fact that they become more attractive the more they are adopted. The competition, therefore, between technologies usually becomes bandwagon, and adoption markets are instability. So, it is very difficult to predict what kind of technology is adopted.

It is supposed that one of the futures of marketing science lies in its becoming in its historical social science, since the social process like building business strategies, institutions, and so on is characterized by a path-dependent process, more or less. This process is non-ergodic system : it trailed and cannot shake off the effects of past events, and do not have limiting, invariant probability distribution that is continuous over the entire space. A negative feedback leads to a predictable equilibrium for prices market shares, because such feedback stabilize the economy by offsetting any major changes.

A positive feedback, on the other hand, magnifies the effects of small events. Increasing returns make for multiple equilibria. There is no guarantee that the particular outcome is selected among the alternatives. So, the best one is not always selected. Once random or chance events select a particular path, the choice may become locked-in regardless of the advantages of

alternatives. The small events of history become important. The minor perturbations specific to an historical contexts, can play an essential role in shaping the eventual outcomes.

Arthur, Ermoliev and Kaniovski [1987] proved that path-dependent systems converge to multiple equilibria which are represented by the stable fixed points, and indicated that historical small events are important. Arthur [1988, 1889, 1990] applied these propositions to the competition among technologies. David [1985, 1986] analyzed the adoption process of a keyboard based on such paradigm.(1)

Next section discusses the reason why historical events are important in the adoption of a technology under what conditions are given. Section III argues the standardization process of a particular technology, especially network externality. Section IV examines the simple case studies on the adoption process of a technology in keyboards and VCRs.

II.Why Are Historical Events Important?

II. 1 Increasing Returns to Adoption

Historical contingency, or non-predictability arises from increasing returns to adoption. According to Arthur [1988], increasing returns to adoption originate from five sources.

1. Learning by using : the more a technology is adopted, the more it is used and the more is learned about it. Therefore, the more it is developed and improved.
2. Network externalities : the effect refers to whether or not there is usage pattern that depends on complementary products, as well as how much customers use it with main product.(2)
3. Scale economics in production : the cost of the products in which a technologies is embodied falls, the more they are pro-

(1) Recently economists examines the comparative institution by using game theory. See, for example, Aoki [1995].

(2) See also Katz and Shapiro [1985, 1986].

duced. Thus the technology becomes more attractive in price as adoption increases.

4. Informational increasing returns: the technology that is more adopted enjoys the competitive advantages, because more people are better known and understood.
5. Technological interrelatedness: as a technology becomes more adopted, a number of other sub-technologies and products become part of its infrastructure. This leads to competitive advantages in the sense that other technologies, which are adopted less, may lack the requisite structure, or may require the other technologies' infrastructures.

Increasing returns to adoption, whatever the source is occurs, characterize the competition between technologies. A particular technology is adopted by a small historical event, and gains an advantage. Given other circumstances, a different technology might have been favored early, and it might have dominated the market. Thus, there are multiple equilibria. To ascertain how one of outcomes is selected, we have to keep track of how adoptions of rival technologies are build up.

II. 2 Polya Case

Imagine an urn of infinite capacity to which added balls of two colors, red and white, say. Starting with one red and one white ball in the urn, add a ball each time, indefinitely. The rule is the following; choose a ball in the urn at random and replace it; if it is red, add a red; if it is white, add a white. This process, obviously, has increments which is characterized by path-dependence. The probability that the next ball adds is red is some function of the proportion red at any time. Polya process settles down to a fixed point which is a random variable uniformly distributed between 0 and 1.

We have to know under what circumstances a competing-technologies adoption market is dominated by a single technology.

Now, we would complain the condition according to Arthur's model [1988, 1989]. The situation has two properties: (i) the choice between alternative technologies are affected by the numbers of each adopted at the time of choice; (ii) the small events may exogenously influence the process, so that randomness must be allowed. The state of the market, therefore, may not determine the next choice, but rather the probability of each alternative chosen.

Consider a dynamical system that allows for these two properties. Consider that one of K technologies is adopted each time an adoption is made, with probabilities $p_1(\boldsymbol{x})$, $p_2(\boldsymbol{x})$, ……, $p_K(\boldsymbol{x})$, which the vector of probabilities p is function of $\boldsymbol{x}$, the vector giving the adoption-shares of technologies 1 to K (out of the total number n technologies). The three examples are shown in Figure 1, 2, 3, where $K=2$.[(3)] Now, where the probability of adoption of technology

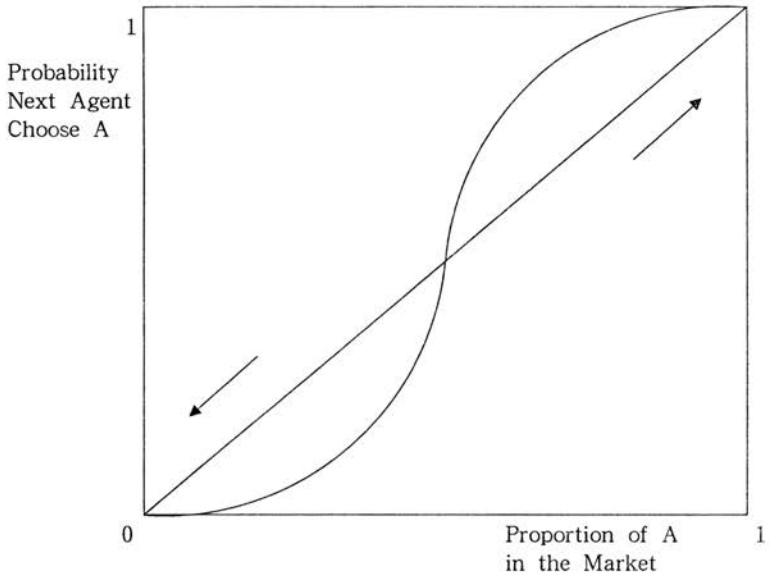

Figure 1 Probability of Adoption in Increasing Returns

(3) In Polya case the color of the ball to be added next is unknown,↗

A is higher than its market share, there would be a tendency in the adoption process for A to increase in proportion; and where it is lower, there would be a tendency for it to decrease. If the share of adoption A settle down at a fixed point of the adoption function.

In Figure 1 the possible long-run share are 0 and 1 for the func-

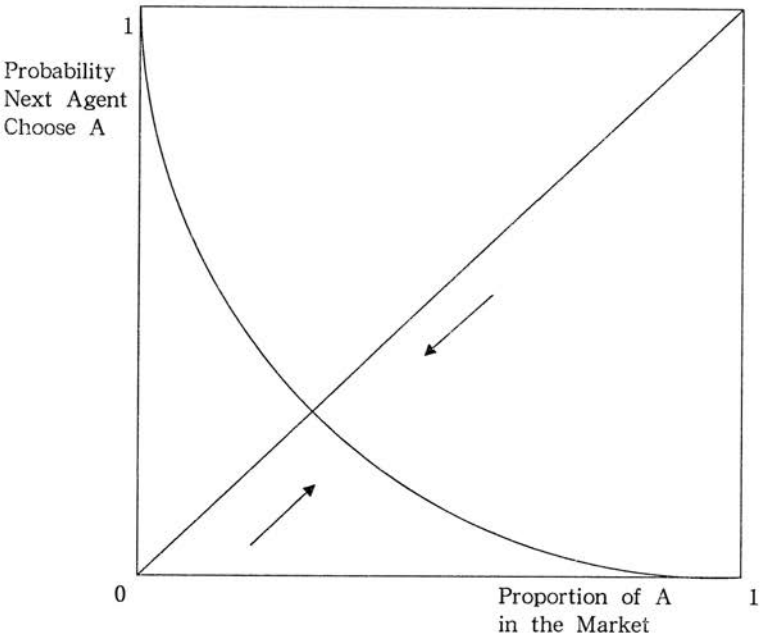

Figure 2　Probability of Adoption in Diminishing Returns

↘but the probability of a given color increases the probability of a given color depends on the current proportions of colors on the table. If an increasing proportion of balls of a given color increases the probability of adding another ball of the same color, the system can demonstrate positive feedback.

Arthur, Ermoliev and Kaniovski [1987] proved the proportions of each color must settle down to a fixed point as balls continued to be added. The probability of each color is equal to the proportion of the color balls. Increasing returns allow several such sets of fixed points.

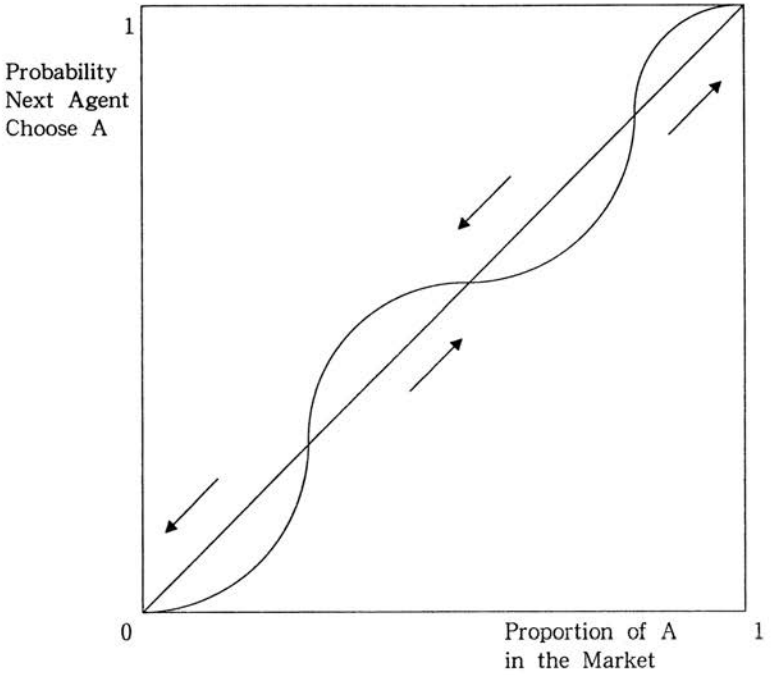

Figure 3 Probability of Adoption in the Combination of Increasing and Diminishing returns

tion p_1. Where there are two fixed points as Figure 1, which one is selected depends upon the cumulation of the random or chance events that occur along the way. Generally, when diminishing returns occur, there is a single epuilibrium point as shown by Figure 2. A combination of increasing and diminishing returns yields many equilibrium points as shown by Figure 3.(4)

II. 3 When Will Technological Monopoly Occur?

Figure 4 showed how potential adopters distributed over adoption payoffs.(5) An adopter is chosen at random from this probability

(4) Arthur [1990], p. 84.
(5) Arthur [1988], p. 600.

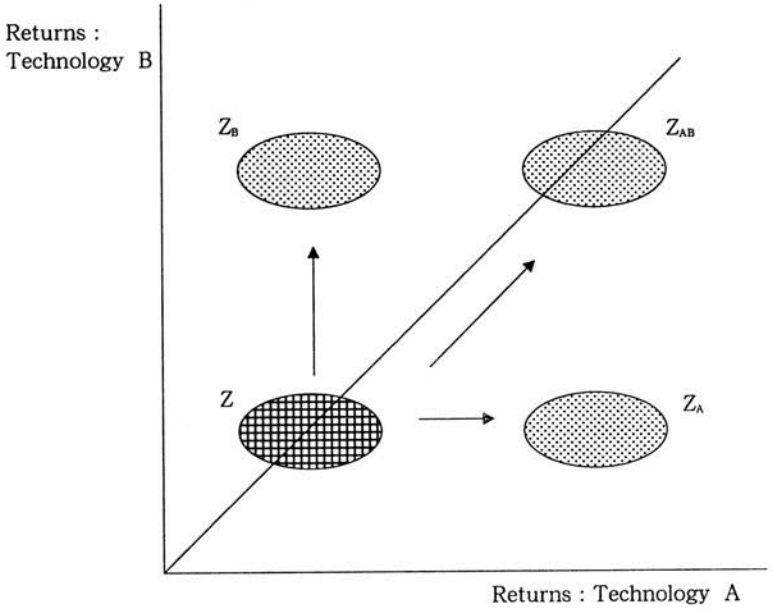

Figure 4　Returns of Technology A and B

distribution each time a choice is made; the distribution itself shifts to the right or upward as returns of technology A or B increase with an adoption of either A or B respectively. When two technologies lead to a shared market, adopter-type-payoff straddles across the 45° line.

Under what conditions is one technology shut out the others or shared with alternative one? With unbounded increasing returns a monopoly by a single technology arises. But when returns to adoption increase but are bounded, as when learning effects eventually exhausted, two technologies share market. In this case, certain sequences of adopters could bid the returns to both technologies. When both reach their increasing returns ceiling, both technologies exist together. Thus with increasing returns to adoption that are unbounded, some eventual histories will lead to share market.

III. Technological Standardization

III. 1 Standards

The term "standards" is to be defined, for the present purposes, as a set of technical specifications adhered by a producer, either tacitly or as a result of a formal agreement.(6) The establishment of standards has the greatest significance when agents cannot assimilate without costs all the relevant information about the commodities that may be exchanged with other agents, and the processes by means of which those goods and services can be produced.

Standards which can be seen as information save transaction costs. They can lower transaction costs by making it simpler for all the parties, users and producers, to recognize what is been dealt in, and also by limiting the scope for the exploitation of information asymmetries. The establishment of standards realizes economies of sbale, as well as reducing transaction costs.

Standards may be established by the following:(7)

1. Unsponsored standards: these are specifications that have no identified originator holding a proprietary interest, or any agent or user initially has little influence with the way of pricing and technologies choice.
2. Sponsored standards: where one or more sponsoring agents hold a direct or indirect proprietary interest, are created. inducements for other firms to adopt particular sets of specifications.
3. Standards agreements are arrived at within, and published by voluntary standards-writing organizations.
4. Mandated standards are promulgated by regulatory authority as governmental agencies.

The first two emerge from market-mediated processes and are

(6) David [1987], p. 211–217.

(7) David and Greenstein [1990], pp. 3–24. They surveyed papers on standard–setting processes in detail.

referred as *de facto* standards. The last two are tagged as de jure (through legislative mandate, or legal ruling). This paper mainly analyzes the unsponsored process, because the process serves as benchmarks that focus the implications of underlying technical features of a product market such as complementarities in demand, or network externalities in use, and of an industry's production process such as technical interrelatedness, or learning spillovers.

Polya case as mentioned above is path-dependent, in the sense that the emergent standard depends on the details of historical sequences in which individual choice was made, that is, on the path the process of adoption took. The process in which an equilibrium, i. e. *de facto* standard, is selected among multiple ones is sensitive to the chance events which dominate in the early adopters' decisions. Consequently, the shares of the different technologies are determined in the growing installed base.

III. 2 Network Externalities

The adoption process in the unsponcered case depends on the lack of the ability to internalize the benefits associated with a particular technology, as well as the source of positive feedback, i. e. increasing returs to adoption. On the other hand, in the sponsored case a sponsoring firm might be able to internalize all the benefit by lowing price in order to discourage later adoptions.

With *de facto* standards, the main sources of increasing returns are network externalities and technological interrelatedness. Network externalities cannot fully internalized by any one among agents, and accrues to the increased network size. The network are provided by firms which determine network size in advance. It pays firms to provide large networks if potential adopters expect these to be large. If prior to adoption, sufficient numbers of agents expect that a paricular network will have a large share, as Katz and Shapiro [1985, 1986] showed, there could be multiple sets of eventual network adoption shares that fulfill prior expectations.

Therefore potential adopters change their expectations as the

fortunes of alternatives change during the adoption process itself. It is supposed that agents form expectations in the shape of about the adoption process. They form probabilities that are conditioned on the numbers of current adoptions of the alternatives. These probabilities, or beliefs, change as the adoption market changes. If one standard gets ahead by chance in the early stage of the adption, its increased probabilities of doing well in the adoption market will enhance expectations of its success.

Thus, even a small lead by a particular alternative becomes important, not only because of network benefits in the present, but also because early adopters expect it to have large network benefits in the future. The conceptual paradigm based on these model of increasing returns turns our eyes to several empirical case studies, because crucial early events shaped the adoption and development of standards over time.

The larger buyers use a particular technology or standard, the more benefits every one gain are enough to justify the each costs of adopting the standard. However, if only a fraction of users adopt it, it may insufficient gains from the new standard enough to justify adoption of standard. Hence, there can be two polar cases; every one adopts the new standard, or nobody does. How will either outcome be selected?

Farrell and Saloner [1985, 1986] showed all users will switch to the new standard and would be better off if they have perfect information about the others' preference. Because under the full information each user anticipates everyone else's switching decision after another switches, in a sequence from those with the largest gains to those with the largest network gains. This coordination problem is referred to as bandwagon effect. In the model with a positive feedback, it is showed that early users can influence benefits to the choice of later ones and can exert strong leverages over the adoption process.

On the other hand, under the uncertainty about others' preferences Farrell and Saloner [1985, 1986] showed that either inertia or

excess momentum occurs. The former arises when no user is sure that others switch to a new standard, and is unwilling to commit to switch without more assurance, the process of which is bandwagon. Excess momentum occurs when early adopters influnce the choice of later ones, so that second-movers switch, even where the total benefits is lower by switching to a new standard. Thus, lack of knowledge about others' preferences interfere with coordination. At the same time the divergent marketing policies, such as promotional pricing, advertising and the modes of standards-sponsorship, might undermine standardization agreements.

IV. Some Case Studies

IV. 1 The Case of QWERTY

We can explain the set of events and varied sources of increasing returns that led to dominance of the standard. A path-dependent sequence of changes is one in which important influences on the eventual outcome can be exerted by small historical events, which includes happenings dominated by chance rather than systematic forces. In non-ergodic situations historical accidents cannot be ignored ; the dynamic process itself takes on an essentially historical character.

David [1985, 1986] showed how the interaction of uncoordinated decisions by users, typing schools, and typewriter manufacturers lead to the adoption of the QWERTY keyboard layout. The QWERTY keyboard is inferior as Apple advertising copy says, "Dvorak Simplified Keyboard (DSK) let you type 20–40% faster," but a switch from the QWERTY to DSK was not induced.

It must be noted that a typewriter involved typewriter operators as well as typewriting machines in the 1880s. Therefore, the decision-makers concerned with typewriters included buyers of typewriter hardware, typists who supplied skilled labor services, and the variety of private or public organizations, undertaking to train people. The typewriter boom beginning in the 1880's brought a proliferation of keyboard arrangements rivaling Sholes-Remington

QWERTY. But by the middle of the next decade the QWERTY keyboard moved to the standard.

In 1882 the New York firm of Wyckoff, Seamans & Benedict, which had bought the world-wide sales agency rights for the Remington Type Wrighter from Remington & Sons, followed a strategy aimed at forming as large a network as possible, beginning to promote by training young women.

They could find employment quickly. Remington schools for typewriting joined the private business and stenographic colleges in all the leading cities. The advent of touch typing gave rise to three features of the evolving production system that were crucially important in causing QWERTY to become locked in as the *de facto* standard of the keyboard.(8) They are technical interrelatedness, irreversible of investments, and economies of scale. They are sources of increasing returns to adoption as Arthur suggested.

In this situation technical interrelatedness refers to the need for the compatibility between keyboard hardware, and the software which was represented by touch-typist's skill of a particular arrangements. It means that the expected value of a typewriter depended on the availability of compatibility of software created by typists' skills. Prior to personal market for typewriters the buyers were firms. They had few incentives for invest in human capital, because their employees acquired skills for typewriters elsewhere.

The investment decision of would-be touch typists was beyond the individual preference. The buyers by potential employers of pended QWERTY keyboards had positive externalities to compatibly trained touch-typists. Typists' incentives to learn the QWERTY keyboard depended on installed base of QWERTY hardware by employers. By increasing the likelihood that such hardware would be installed than others, such a decision raised the probability that prospective typists would opt to be trained in a QWERTY keyboard.

The occurrence of lock-in QWERTY as early as the mid-1890's

(8) David [1985, 1986].

owed to high switching costs to other new keyboard designs and the resulting quasi-irreversibility of investments in specific touch-typing skills. The human capital formed in learning to touch-typing is very durable, for once mastered it is long retained and may be upgraded by learning-by-doing. Moreover, once a specific skill acquired it becomes quite costly to switch to a different program. Thus as keyboard conversion costs concerned, an important asymmetry appeared between the software and hardware components of the evolving typewriting system.

These conditions, technical interrelatedness and irreverdibility of investments, gave rise to scale economies, which resulted in *de facto* standardization through the predominance of QWERTY keyboard design. Economies of scale were exploited by the private business colleges which taught young people to touch-type through the use of manuals.

This case is likely to be governed by historical accidents by the particular sequences of choices made close to the beginning of the adoption process. Random factors tend to exert great leverage under increasing returns. Even though the initial lead acquired by Remington was slender, the industry would lock-in to *de facto* standard.

IV. 2 The Case of VCRs

Under increasing returns or bandwagon effects, network effects is larger than first-mover advantages. Ampex Corporation, which was a small company in California, invented a video recorder for broadcasting applications in 1956.(9) But design technologies for video recording had been difficult for Ampex to master and to protect from selected handful of companies that made audio tape recorders and invested in development of video recording.

The characteristics of home video was that it would require many years to establish efficient mass production capacity, broad

(9) See Rosenbloom and Cusumano [1987] for the birth of the VCR industry, and the Japanese firms' advantages over other countries' ones.

distribution channel, and clear market preferences because of mass market global nature as well as the product's technical complexity. The source of increasing returns to the adoption of a particular technology is network externality ; buyers will tend to choose the VCR that has been chosen, or appears likely to be chosen by many other buyers, given other thing, e. g. cost and capabilities, equal. By positive feedback the more perceived benefits of choosing a particular standard increases, the more buyers choose it. This create a dynamic mechanism

In the VCR standardization competition, there are three types of agents : the first is Sony, JVC (the Victor Company of Japan ; the subsidiary of Matsushita), Philips, which are sponsors of the three rival formats and producers of the core products, the second is the remaining consumer electronics producers, each of whom adopt one of the standard formats of production and/or distribution, the final is the producers and distributors of a complementary product, e. g. prerecorded software.[10] Philips adopted a different format in Europe, but it never pose a challenge to Beta adopted by Sony and VHS adopted by JVC.

The annual production units and cumulative production units of Beta format vs. VHS format from 1975 to 1988 are shown in Figure 5, 6.[11] Although Beta appeared first, and gained 58% of the market in 1975-77, VHS exceeded it in 1978 and the share of Beta fell every year. After its share was four-to-one of the share of VHS in 1984, Beta began a rapid decline to extinction. In a second phase of rivalry in the 1980s, the alignment of producers of complementary products reinforced the VHS advantage.

Although in the initial stage Sony gained a lead, it tried to enlarge the network in adopting the Beta, concentrating especially to win Matsushita and RCA to its side because it was recognized

(10) This case study of VCR is based on Cusumano, Mylonadis, and Rosenbloom [1992].

(11) Figure 6 and 7 depend on the table of Cusumano, Mylonadis, and Rosenbloom [1992], p. 54.

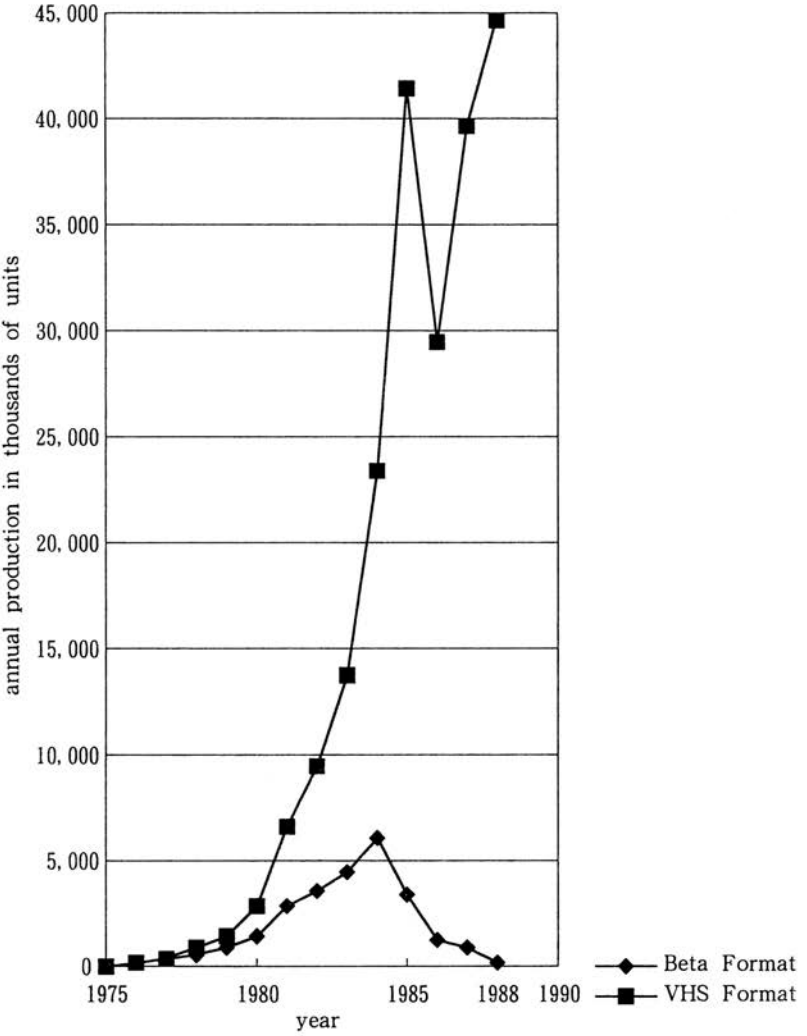

Figure 5　Beta vs. VHS

that no producer, on its own, could establish a VCR standard. But both firms questioned the adequacy of a one-hour playing time by Beta, and did not make a commitment to the market. In addition when in 1975 Hitachi showed an interest in licensing Beta, Sony

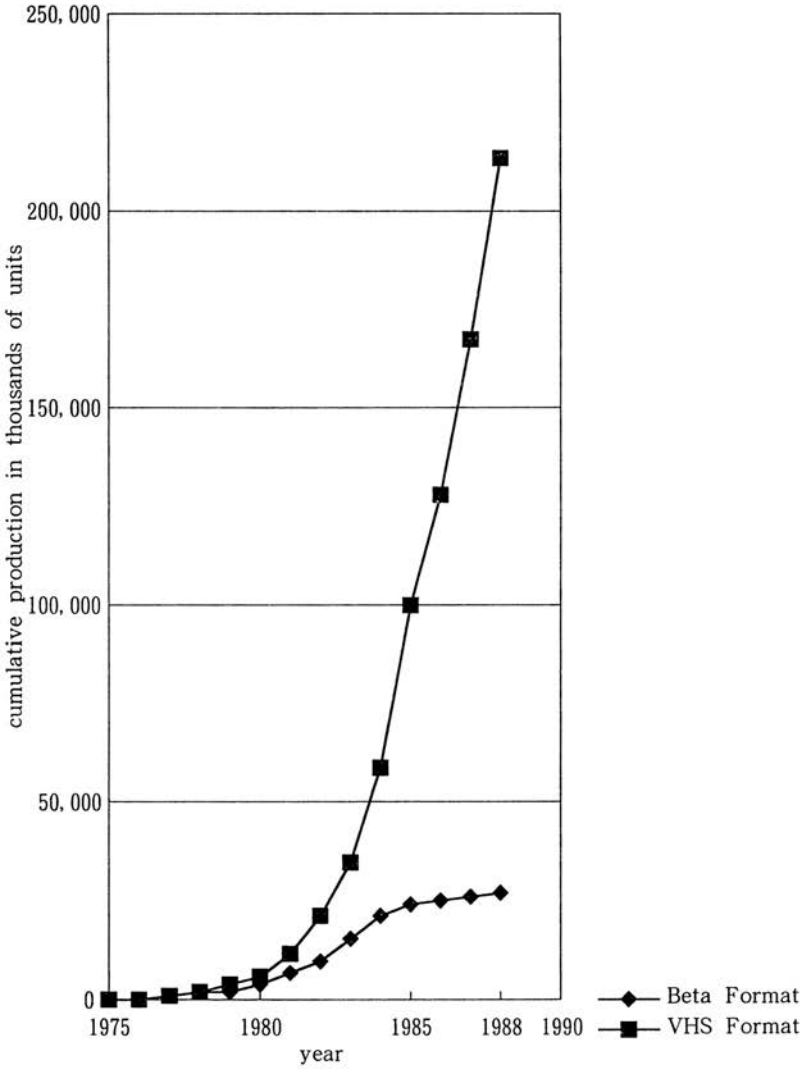

Figure 6 Beta vs. VHS

refused it. Sony had uniquely innovated with consumer products that incorporated advanced electronics, but was reluctant to help potential licensees with OEM shipments. Moreover Sony was pri-

mary interested in persuading Matushita to adopt Beta rather than Hitachi, because JVC was working on a competing format, VHS.

MITI (Japan's Ministry of International Trade and Industry) favored Sony, since it alread had a machine in the market. Toshiba and Sanyo agreed to Beta, but the other firms decided to wait for VHS, which JVC announced in 1976.

On the other hand, JVC was technologically inferior to Sony. To catch up to Sony, JVC followed a strategy enlarging the network of VHS including exports, aggressively pursuing both licensing and OEM agreement. In 1976 JVC had lined up Hitachi, Mitsubishi, and Sharp, as well as Matsushita. JVC entered into an OEM relationship with Matsushita, since it did not have enough capacity to supply Matsushita's huge distribution network and also Matsushita had enough capacity to produce VHS machines on its own within a few months. In addition, JVC provided machines to Hitachi, which Sony would not, and supplied Sharp and Mitsubishi, which Hitachi had helped to recruit.

JVC pursued the alliances in global markets as well as Japan, by which the VHS network was enlarged. But the U. S. company rejected JVC's offer for an OEM relationship because of its small production capacity. So JVC turned toward European firms which would be smaller quantities. It was recognized that the manufacturers who dominate the world market would be the company which captured the largest share of the U. S. market, where the major firms were likely to be RCA and Zenith. Zenith established a relationship with Sony. RCA wanted lower priced machine as well as a longer recording time, at least three hours. Matsushita, which took a interest in RCA's distribution network, achieved the increase in playing time in two months. In 1977 Matushita had an agreement to supply RCA.

Matsushita's alliance with RCA changed the nature of competition. U. S. distributors initially had been indifferent to the choice of standards and appeared to wait for clearer market signals. They appeared to consider that low price, massive capacity to deliver

and the longer playing time were more important. Matsushita solved these points. This was why VHS group were able to establish an better image than Sony. Thus by 1977 the VHS group, especially Matsushita could enter into worldwide market, and begin exploiting its technology and investment in low-cost manufacturing and mass distribution earlier than Sony.

The VCR have three functions; recording broadcast programs, making home videos, and playing prerecorded movie cassette. VCR achieved mass-market penetration in Europe earlier than U. S., Japan, and elsewhere, because of the availability of fewer broadcast channels. In 1983 the penetration reached 10 percent in U. K., because TV set rental was business practice; 10 percent in U. S. and 12 percent in Japan. The alliance formed by JVC and Hitachi with Thorn and Granada, the leading British TV-rental operations, led distributors to adopt the VHS format in tape rentals over Beta.

In 1978 RCA, which belonged to the VHS group, developed an important alliance with Magnetic Video Corporation (MV), which was a leader in prerecorded video, to enter the ambitious videodisk market. Matsushita supplied MV and others with the equipment for high-speed duplication and low-cost deck. When Granada, British firm, entered into the rental market in U.S., it offered VHS players and cassettes. Sony followed the same strategy as Matsushita, but with a lag and with less effecs. As a consequence, the VHS format dominated Beta in prerecorded video cassettes by 1984. Zenis switched from Beta to VHS in 1984.

As mentioned above, the technical superiority of the compact Beta format by Sony notwithstanding, the eventual dominance of VHS format as industry standard emerged from the interplay of adventitious and seemingly unrelated conditions and events; first, the legacy of prior relations between Sony and Hitachi, second, the incidental ability of VHS to carry a tape with a longer playing time, third, the introduction of prerecorded video cassettes. The first two are associated with network externality, the third is associated with technical interrelatedness.

V. Concluding Remarks

This paper examined the dynamical adoption process of a particular technology that selects an equilibrium from multiple ones under increasing returns by random historical events. Increasing reutrns can cause the economic system to lock-in an outcome not necessarily superior to alternatives. A new and superior technology does necessarily compete to replace an old and inferior ones.

Under increasing returns competition between technologies takes on an evolutionary character or path-dependent. History becomes important. This is why this paper examined the case of QWERTY and VCR. These cases shows that the cumulation of small random events drive the adoption process into an outcome, which is not necessarily the most desirable.

Does the exit into superior equilibrium occurs if an industry is locked-in an inferior technology ? It depends on the self-reinforcing mechanism, that is, the degree to which the advantages by the inferior technology are reversible to an alttrnative.[12] Where relationshipspecific resources like learning effects are the sources of reinforcement, advantages are sunk and not transferable to an alternative technlogy.

On the other hand, where coordination effects are the source of lock-in, advantages are often transferable. For example, users of a particular technological standard may agree that another would be superior, if everybody switched. If the current standard is not embodied in specialized equipment and its advantages are convention or inertia, a negotiated or a mandated switching to a superior collective choice can provide exit into new equilibrium at negligible cost.

Farrel and Saloner [1985, 1986] showed that each user will decide independently, as long as each has certainty that others also prefer the alternative. But if users are uncertain of others' preferences,

(12) Arthur [1990].

excess inertia can occur that is, each user would benefit from switching to the other standard, as long as the other users change, but individually none dare change it at the head. For example, when in electronics consumer products most of users are certain that analogue changes to digital, each user decide to change analogue VCR to a digitalone.

I have indicated that competing technologies are example of self-organizing. In Polya case the colors of balls are technologies. Discussions in this paper would be applied to the choice of a particular institution or organizational mode.(13) The colors of balls are institutions or organizational modes in such a case. It is path-dependent character, and has multiple equilibria. A particular institution or organizational mode would be selected by historical events, which is not necessarily superior to alternatives, and not entirely predictable in advance. So, history would also be important.

REFERENCES

Aoki, M. [1995], "An Evolving Diversity of Organizational Mode and Its Implications for Transitional Economies," *Journal of the Japanese and International Economics*, 9(4), December, pp. 330–353.

Arthur. W. B. [1988], "Competing Technologies: an Overview," in G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds), *Technical Change and Economic Theory*, Pinter, pp. 590–607.

Arthur. W. B. [1989], "Competing Technologies, Increasing Returns, and Lock-in by Historical Events, *The Economic Journal*, 99, March, pp. 116–131.

Arthur. W. B. [1990], "Self-Reinforcing Mechanisms in Economics," in P. W. Anderson, K. J. Arrow, and D. Pines, *The Economy as an Evolving Complex System*, Addison-Wesley, pp. 9–31.

Arthur. W. B. [1990], "Positive Feedback in the Economy," *Scientific America*, February, pp. 80–85.

Arthur, W. B., Y. M. Ermoliev, and Y. M. Kaniovski [1987], "Path-dependent Processes and the Emergence of Macro-structure," *European Journal of Operations Research*, 30(3), June, pp. 294–303.

(13) For example, Chiaromonte and Dosi [1993]. See also David [1993], Foray [1993].

Chiaromonte, F. and G. Dosi [1993], "The Micro Foundations of Comptetitiveness and Their Macroeconomic Implications," in D. Foray and C. Freeman, *Technology and the Wealth of Nations*, Pinter, pp. 107–134.

Cusumano, M. A., Y. Mylonadis, and R. Rosenbloom [1992], "Strategic Maneuvering and Mass-market Dynamics: The Triumph of VHS over Beta," *Business History Review* 66, Spring, pp. 51–94.

David, P. A. [1985], "Clio and the Economics of QWERTY," *American Economic Review*, 75(2), May, pp. 332–337.

David, P. A. [1986], "Understanding the Economics of QWERTY: The Necessity of History," in W. N. Parker, *Economic History and Modern Economist*, Basil Blackwell, pp. 30–49.

David, P. A. [1987], "Some New Standards for the Economics of Standardization in the Information age," in P. Dasgupta and P. Stoneman [eds.], *Economic Policy and Technological Performance*, Cambridge University Press, pp. 206–239.

David, P. A. [1993], "Path-dependence and Predictability in Dynamic Systems with Local Network Externalities: A Paradigm for Historical Economics", in D. Foray and C. Freeman, *Technology and the Wealth of Nations*, Pinter, pp. 208–231.

David, P. A. and S. Greenstein [1990], "The Economics of Compatibility Standards: An Introduction to Recent Research," *Economics of Innovation and New Technology*, 1 (1), July, pp. 3–41.

Farrel, P. A. and G. Saloner [1985], "Standardization, Compatibility and Innovation," *Rand Journal of Economics*, 16(1), Spring, pp. 70–83.

Farrel, P. A. and G. Saloner [1986], "Installed Base and Compatibility: Innovation, Product, Preannouncement, and Predation" *American Economic Review*, 76(5), December, pp. 940–955.

Foray, D. [1993], "General Introduction," in D. Foray and C. Freeman, *Technology and the Wealth of Nations*, Pinter, pp. 1–22.

Katz, M. and C. Shapiro [1985], "Network Externalities, Competition, and Compatibility," *American Economic Review*, 75(3), June, pp. 424–440.

Katz, M. and C. Shapiro [1986], "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy*, 94(4), August, pp. 822–841.

Rosenbloom, R. S. and M. A. Cusumano [1987], "Technological Pioneering and Competitive Advantage: The Birth of the VCR Industry," *California Management Review*, XXIX (4), Summer, pp.51–76.