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Property Rights and the New Institutional Arrangement for Product Innovation in Silicon Valley

TAKIZAWA Hirokazu
RIETI

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Hirokazu Takizawa
Toyo University & RIETI

Abstract

This paper surveys researches on the new institutional arrangements for product innovation emerging in Silicon Valley. Special reference is made to the characteristics that go beyond the traditional property rights framework. First, the complicated patterns in allocation of control rights observed in VC contracts are examined to show the limit of Grosman-Hart-Moore framework. Second, the unique informational arrangement in Silicon Valley is explained as a second-best solution to the team-theoretic coordination problems in modular environments. Third, the paper examines the mechanism of ex post evolutionary formation of a product system. The paper concludes by suggesting future direction for research, including further research on the role of innovation commons in this process.

Key words: Venture Capital Contract, Modularity; Tournament Game, Intellectual Property Rights

JEL classification: D21, L23, O32, P51, P52

1. Introduction

Silicon Valley has long been successful in bringing a lot of outstanding entrepreneurial firms into existence. Among them are high-tech firms such as Hewlet Packard, National Semiconductor, Intel, Advanced Micro Devices, Apple, Sun Microsystems, Silicon Graphics, Oracle, 3Com, Cisco Systems, etc. More recently, such leading firms in Internet/Web services as Netscape, Yahoo, and e-Bay have been funded and nurtured in Silicon Valley. Compared with other high-tech industrial districts like Cambridge in the UK, Silicon Valley is undoubtedly the forerunner in the domain of product system innovation.[1]

The recent dot.com bubble and crash seem to have soothed the previous enthusiasm for Silicon Valley. It should be noted however that the mechanism for product system innovation in Silicon Valley had shown its effectiveness well before those events, and the crash just reverted things back to the way they had been. The mechanism still invites serious interest from policymakers around the world who want to create a mechanism for nurturing entrepreneurial firms, and thus deserves to be elucidated. What mechanism makes Silicon Valley a major driving force for product system innovation, especially in the information and communications industry? Is it fully understandable within the framework of traditional economic theories? What lessons can we draw from it for other industries/localities? The purpose of this paper is to analyze the working of this mechanism, and to explore implications that can be deduced from the analysis. This paper is not meant for presenting a fully new contribution by itself, but for drawing a whole picture of the mechanism and further exploring its implications mainly based on Kaplan and Strömberg (2002), Aoki (2000; 2001), and Baldwin and Clark (2000).

The institutional arrangement for product system innovation emerging in Silicon Valley has several characteristics, which go beyond traditional economic principles. First, the Silicon Valley firms are difficult to understand within the framework of property rights

[1] In what follows, we refer to a good or service that as such forms a system, like a computer or various Internet/Web services, as a 'product system'. As will be argued in Section 4, it has a huge implication for our economic activities that very complex product systems have today become an object of mass production/consumption.

theory as set by Grossman and Hart (1986) or Hart and Moore (1990). Regarding the ownership of physical assets as the defining factor for the boundary of the firm, they assert that the distribution of ownership over physical assets structures fundamental governance of the firm. Their argument is, in a sense, in line with the conventional wisdom that exclusive control right that comes with ownership is the premise of proper functioning of market economy. However, the venture capital contracts observed in Silicon Valley are characterized by the complicated patterns in allocation of various control rights among entrepreneurs and venture capitalists, where the ownership of physical assets seems to be less important than in traditional firms. Second, the informational arrangement observed in Silicon Valley is unique in that there are substantial degrees of decentralized information sharing across competing entrepreneurial firms on the one hand, and information hiding (encapsulation) on the other (Saxenian 1994). This informational arrangement is also difficult to explain by the traditional property rights theory. However, understanding these ostensibly contradictory phenomena seems to be the key to understanding the Silicon Valley model. Third, examination of the nature of the product system innovation in Silicon Valley is now inviting a serious interest in the role of patent/copyright system in innovation. It has come to be recognised that, while incumbent firms loby for strengthening the current intellectual property rights, it can hurt new innovators' incentives to innovate. Although many still remain to be debated, we may say at least that, when it comes to ideas, the allocation and perfect enforcement of exclusive property rights over them may not necessarily assure social efficiency of economic activities.

The organization of the chapter is as follows. Section 2 presents the background facts about the mechanism for product system innovation in Silicon Valley. Section 3 focuses on venture capital contracts that govern the relationship between an entrepreneur and a venture capitalist. A close look at real-world venture capital contracts reveals complex allocation of various rights between an entrepreneur and a venture capitalis. Section 4 explores another important aspect of the Silicon Valley model: modularity in the architecture of product systems. Based on Baldwin and Clark (2000), this section mainly explores the non-incentive aspects of modular architecture. Section 5 argues that modular architecture is indeed complementary to the organizational arrangement found in Silicon Valley—the unique mixture of decentralized information sharing and information encapsulation. Section 6 focuses on the incentive to innovate in the modular environments. Section 7 concludes.

2. The Silicon Valley Model

The strikingly innovative nature of Silicon Valley could be best exemplified by the computer industry. Between its onset in the 1940s and the mid-1970s, the computer industry was virtually a monopoly market dominated by IBM. However, in the mid 1970s, a group of entrepreneurial firms, mostly small or medium sized and funded by venture capitalists, were set up and were very agile in R&D activities. The apparent feature common to those entrepreneurial firms is that they usually specialize in the development and production of modular components of a product system, instead of competing with IBM by producing a stand-alone product system. Thus many sub-industries have been formed within the domain of the traditional computer industry. Various R&D activities previously conducted within IBM have come to be conducted independently by small entrepreneurial firms outside. Although the major product in this industry has since then shifted from a mainframe to minicomputer, to personal computer, and to network computing, the decentralized structure that emerged in the 1970s still persists in this industry.

Along with such changes in the industrial organization of the computer industry came a new way of product system innovations. Today a new product system is consecutively formed by selecting and combining ex post new modular component products developed by entrepreneurial firms. In this sense, we may say that a novel and unique economic institution has emerged in the domain of product system innovation in the computer industry. Aoki (2000; 2001) calls the theoretical conceptualization of this mechanism of the product system innovation the 'Silicon Valley model' after the name of the place that has most typically embodied this mechanism.[2]

In Silicon Valley, there are networks of people and institutes ready to help start-up firms, such as universities, research institutes, specialized suppliers, lawyers, accountants, head hunters, and venture capitalists. These actors have important roles in nurturing start-up firms respectively, collectively providing a smooth environment for product system

2 Bresnahan (1999) also express the emerging innovation mechanism of product systems by the term 'Silicon Valley model'. These words are used in contrast to the 'IBM model' in which an integrated firm like IBM completely controls a platform with an exclusive role in the coordination of innovations. He says, 'In the 'Silicon Valley' form, distinct technologies are advanced by a wide number of different firms. Interface standards, cross-company communication, and markets have been used when supply is by a group of vertically disintegrated specialty technology firms' (ibid:225).

innovation. However at the center of the entrepreneurial process in Silicon Valley is the relationship between entrepreneurs, who have promising ideas but lack enough money, and venture capitalists, who seek promising investment projects.[3]

When an entrepreneur comes across a new idea, it is still highly uncertain whether it can create any value in the market. A venture capitalist, faced with such a would-be entrepreneur, judges the idea's marketability based upon consideration of the entrepreneur's personality, talent, the originality of the idea, and recent trends in technology etc. Thus, a venture capitalis takes a screening role, where processing of various 'tacit knowledge' is especially important. The relationship between an entrepreneur and a venture capitalist begins when the venture capitalist judges the idea to be promising. It should be noted that a venture capitalist often funds multiple entrepreneurs in the same niche market, which creates a tournament like situation among the entrepreneurs. If the project turns out to be successful, the entrepreneurial firm will either go to the public, or be acquired by some leading firm, bringing the entrepreneur and the venture capitalist a huge amount of prize. At this stage, most knowledge concerning the business of the firm turns into 'codified knowledge' that is accessible to the public. Thus the process of venture capital financing is, simply put, that of transforming a tacit knowledge into a codified knowledge. [4]

The roles of venture capitalists vis-à-vis entrepreneurs in this process are not confined to that of funding. They usually include a wide-ranging service for entrepreneurs. First, they play an important role in the governance of the firm they fund, which is mainly structured by a venture capital contract. At the time of start-up, venture capitalists usually provide

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[3] In purely financial terms, venture capital funds are a financial intermediary that channels a large amount of capital from other financial institutions into entrepreneurial firms. Legally, it is a partnership composed of two classes of partners: general and limited. General partners accept personal responsibility and legal liability for fund management, while limited partners provide most of the fund, but are not involved in the management. Although funds are usually maintained only for a fixed period of time, venture capital companies are often formed by general partners to maintain managerial continuity.

To be more precise, venture capital funds do not usually fund an entrepreneurial firm at too early a stage in its development to secure their investment; angel investors fill the need for such smaller amounts of start-up capital. See Mayer (2001) for how angel investors and venture capitalists differentiate their working fields. However in Silicon Valley, there is a very close relationship among angel investors, venture capital funds, and venture capital companies. Thus I will not explicitly distinguish among them and refer to them all simply as 'venture capitalists' in the present paper.

[4] In the process of transforming a tacit knowledge into a codified knowledge, relational financing is more effective than arm's-length financing. See Aoki (2001, Chapter 12) for the argument.

only a fraction of capital that is needed for the completion of the project, called 'seed money', with the expectation that the additional financing will be made stepwise, contingent upon the project proceeding smoothly. This is what Sahlman (1990) called 'staged' capital commitment. Such an arrangement enables venture capitalists to exercise an exit option by refusing additional financing when the prospect of the project has turned unpromising, while the entrepreneur can increase his/her ownership share if certain performance objectives are met. Venture capitalists are well represented on the boards of directors of the start-up firms and play a conventional role in structuring its governance, often firing the founder-manager when needed. As a result, it is not rare at all that the founder-manager loses the managerial position. Section 3 considers issues concerning venture capital contracts in more details.

Second, in addition to the governance role, venture capitalists provide a wide range of advice and consulting services to senior management of the start-up firms; help to raise additional funds; review and assist with strategic planning; recruit financial and human resource management; introduce potential customers and suppliers; and provide public relations and legal specialists. The commitment of a venture capitalist can be so deep and wide-ranging that his/her intervention may be sometimes regarded as an essential ingredient for a company's success.[5]

Third, related to the second, venture capitalists play an important role in providing and mediating the most recent technological information to the entrepreneurs. Venture capitalists are often themselves successful entrepreneurs with enough technological expertise to provide such services. Since the speed is important for their business, informal exchange of technological information not yet open to the public is often critical. The geographical agglomeration of universities, research institutes and specialized suppliers in Silicon Valley provides venture capitalists and entrepreneurs with a great advantage in this regard.

Recent start-up firms tend to become targets of acquisition by leading firms, which are often themselves grown-up entrepreneurial firms that had been successful in assuming

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5 See Lee, Miller, Hancok, and Rowen (2000, Chapter 13) for examples. Venture capitalists even engineer a merger between start-up firms in their own portfolio, as Kleiner Perkis did to Excite and @Home.

leadership in their niche markets. The purposes of acquisition are usually either to kill potential sources of challenges or to strengthen their market positions by shortening the period of in-house R&D by so-called A&D (Acquisition and Development). The acquiring leading firms also seek to bundle complementary technologies to create a new product market.

This tendency is deeply interconnected with the nature of technological development in the information and communications industry. Since the advent of IBM's System/360, new generations of computers have been defined by a definite platform or architecture, which enabled various niche markets to be formed within the traditional computer industry. For the above acquiring mechanism to work well, it is important that each platform has open and standardized interfaces among modular component products, through which firms engaged in respective component products can coordinate their designs. Nowadays, firms often try to propose new interfaces based on the current architecture/platform, leading to increased uncertainty in technology. Thus, there is a strong need for information sharing, which are realized through decentralized information exchange between entrepreneurs and venture capitalists. As a result, a substantial degree of information sharing regarding new trends in relevant interfaces and emerging technologies is observed, while most of the detailed information regarding the development of respective modular products is encapsulated and/or hidden within firms engaged in them. This is essentially the unique mixture of decentralized information sharing and information encapsulation, which Saxenian (1994) regarded as the key to understanding the innovative nature of Silicon Valley firms.

Previously the standardized interfaces had been defined and controlled by a single dominant firm like IBM. Nowadays, however, there are fierce struggles for assuming leadership in setting standard among several leading firms. This is because a market for a new product can now be formed by augmenting a new modular component to the existing product system, by bundling existing modular components, or by unbundling an existing modular component. I will later mention this process as the 'ex post evolutionary formation of a product system'. Standardized interfaces are thus evolutionarily formed in the interaction of firms, large and small. In this process too, venture capitalists as well as the leading firms play an important role in intermediating necessary information among the entrepreneurial firms.

3. Governance of Silicon Valley Firms through Venture Capital Contracts

How are entrepreneurial firms in Silicon Valley governed? A recent study by Kaplan and Strömberg (2002) provides stylized facts and analyses on venture capital contracts based on a sample of 213 venture capital investments in 119 portofolio companies by 14 venture capital partnerships. About 42% of the portfolio companies in their sample are in information technology and software industries, while 15% are in biotechnology/medical industries and 13% are in telecommunications.

The stylized facts they find can be summarized as follows:[6]

(1) Venture capital contracts separately allocate cash flow rights, voting rights, board rights, liquidation rights, and other control rights.

(2) Venture capitalists use various securities for fine-tuning these rights. Convertible preferred stock is most frequently used. Even when common stock is used, venture capitalists get a different class of common stock with different rights from those of the entrepreneurs.

(3) Cash flow rights, voting rights, control rights, and future financings are often contingent on observable measures of financial and non-financial performance.

(4) If the firm performs poorly, the venture capitalists obtain full control. As the firm's performance improves, the entrepreneur retains/obtains more control rights. If the firm performs very well, the venture capitalists relinquish most of their control rights and retain only cash flow rights.

(5) Venture capital contracts usually include non-compete and vesting provisions in order to make it more expensive for the entrepreneur to leave the firm. The vesting provision dictates that the entrepreneur's shares vest over time, while non-compete provisions prohibit the entrepreneur from working for another firm in the same industry for certain time period.

(6) In general, venture capitalists have more board and voting control in later rounds of financing.

It is worth noting that while cash flow right, board rights, voting rights, liquidation rights and other control rights are allocated separately as independent instruments, such property

[6] See also Hart (2001) for a similar summary. However, he says that a venture capitalist has less control in later round of financing.

rights arrangements seem to be far more complex than what the conventional wisdom of property rights suggests. An investment project here can be regarded as jointly owned by an entrepreneur and a set of venture capitalists, and the control rights shift between them as project proceeds and its performance varies in this process

Kaplan and Strömberg use their survey data to test the validity of such recent financial contracting theories as represented by Aghion and Bolton (1992) and conclude that the theories are doing a fairly good job, although real-world financial contracting is far more complex than the prediction of the theories. Indeed, the setting of the Aghion-Bolton model seems to capture some aspects of the real-world situation that an entrepreneur and a venture capitalist face: A would-be entrepreneur has a promising project idea but lacks sufficient wealth, while a venture capital seeks a promising investment project. Venture capitalists have strong incentives to maximize project value with a less concern on private benefit of control, while entrepreneurs may privately benefit from controlling the firm. Thus there is a fundamental need for drawing up an elaborate contract to align their diverse incentives, resulting in a complicated contract.

How should we evaluate these results from the perspective of property rights regimes? Some may suppose that the Aghion-Bolton model is, after all, within the framework set by Grossman and Hart (1986) and Hart and Moore (1994), and so the traditional property rights approach can explain the above empirical results. Certainly the Aghion-Bolton model is within the incomplete contract theory. However, the only asset involved in their model is a project idea, not a physical asset, and the entrepreneur in their model is wealth-constrained. These assumptions make a great difference. The assumptions enable Aghion and Bolton to endogenize allocation of control rights, which Grossman and Hart (1986) and Hart and Moore (1990) regarded as coming automatically with ownership of physical assets.[7]

It seems difficult to explain the governance structure of Silicon Valley firms by focusing exclusively on the distribution of ownership of physical assets, although Hart (1995, pp. 53-54) asserts that the tendency of de-integration observed in the 1980s and 1990s,

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[7] Aoki (1994) also derives contingent governance as the second-best solution to the free-riding problem in teams, where all members of the team are welth-constrained and thus the effective pulishment is limited. In the sense that bailing out is possible, Aoki's model is more realistic.

possibly attribuable to the advances in information technology, can be explained by his theory. He reasons that the increased flexibility in technology has caused relevant assets to be less complementary, leading to de-integration. However, the human capital investment by an entrepreneur is usually essential in the entrepreneurial firms in Silicon Valley, which should naturally lead to the contrary conclusion, i.e., integration, according to his theory.

Another dimension that can be added to the discussion is the perspective suggested by Rajan and Zingales (2000). Traditional firms, which have been extensively studied in the corporate governance literature, typically owned and controlled a large amount of highly specialized inanimate assets, such as plant, machinery, and world-famous brand names. Since these assets were hard to replicate and thus were unique, they defined the boundary of the firm well in both legal and economic terms. Thus, the ownership of unique inanimate assets was primary source of power in the corporation. Human capital was closely tied to these assets and immobile.

Recent trends show that, however, the nature of the firm is changing. In many leading industries, inanimate assets are becoming less and less important, while easily appropriated assets like information and/or human capital are becoming increasingly important. Since in these new types of enterprises the ownership of inanimate assets no longer works as a strong leverage to enforce power over employees, new governance mechanism is required. Rajan and Zingales argue that it is important to identify the critical resource of the firm correctly, and to create a situation where employees are induced to make firm-specific investment by giving them privileged access to that critical resource. [8]

A typical entrepreneurial firm in Silicon Valley seems to fit well with Rajan-Zingales's characteristics of the new enterprise. In most venture capital contracts settings, inanimate assets are unimportant in comparison with those in traditional firms, whereas founder's project idea is the critical resource of the firm, at least at the start-up stage. Thus, it is important to tie the entrepreneur to the firm, while giving entrepreneurs the opportunity to accumulate too much power is dangerous from the financing viewpoints. The complicated nature of this relationship requires a very complicated financial contracting. On the one hand, stock options that vest over time are utilized to tie the entrepreneur to the firm.

[8] See also Rajan and Zingales (1998) for a more technical argument.

Contingent shift in control rights are included in the contracts to make sure that the management of the firm is professionalized. That venture capitalists have more control in later rounds of financing can also be explained from this perspective. Near completion of the project, the decision regarding the timing of going to public or selling the firm to an acquiring firm becomes critical for maximizing value, which requires professionality of the venture capitalists. Note that here the ownership of the firm is utilized less for having residual control rights over inanimate assets, but more for motivating the entrepreneur.

Since more than 50% of the firms in the Kaplan-Strömberg sample are concentreated in information and communications industries, one may doubt the relevance of the above insight to developing contries. However, general lessons drawn from the analyses can be useful even to the emerging markets. First, our discussion deals with the situation where a wealth-constrained entrepreneur with a promising project idea seeks funding by an investor. Such demand is ubiquitous even in developing countries. The above analysis shows us the way that can induce more investors to invest in a promising project. Second, some contries may not allow their laws to do the same things as venture capital contracts do. Indeed, the U.S. laws seem to be more flexible for devising a complex and subtle incentive design than the Japanese commercial law. To the extent that the venture capital contracts in the U.S. are successful, other countries could learn from their working and improve their legal environment.

4. The Power of Modularity

4.1 Modular Architecture

Another important ingredient of the Silicon Valley model is that most innovation occurs within the framework set by a modular architecture of a product system. To be sure, modularity has been particularly articulated in the information and communications industry. However, its broader implications have been explored since the 90s, and these insights on modular environment may be useful to industries other than information and communications industry.

Simply put, a module is a quasi-autonomous subsystem, which constitutes a more complicated system or process combined with other similar subsystems. The way these subsystems are combined is often referred to as a connective rule or interface rule. Modularisation is decomposing a complex system or process into modules that can be designed independently. The best example is a computer system, which is composed of a CPU, an LC monitor, hard disk drive, an OS, and so on. Almost all the communication systems are also modularised, because they are usually realized through combination of component technologies.

To the best of my knowledge, it is Herbert Simon who first pointed out the importance of the concept of modularisation of a complex system, although he did not use exactly the same term (Simon 1962). He considered the production process of a watch to illustrate a generic principle to cope with complexity. Suppose that two watchmakers combine 100 parts to make a watch. Their jobs may be interrupted by such things as phone calls. One watchmaker combines 100 parts in a run, whereas another watchmaker starts with making intermediate parts, each of which is composed of 10 parts, and then completes the watch-making task by assembling 10 intermediate parts. The production system of the latter watchmaker is certainly more efficient than that of the former watchmaker, when random events disturb the continuity of work process. Obviously, in this example, each intermediate part can be regarded as a module. As this example illustrates, modularisation is the mechanism with which boundedly rational humans cope with complexity of a product system.

This naturally leads us to the question: Why renewed interest in modularity? I think the main reason for this is that we have only recently come to produce and consume a very complex system product on a large scale. Furthermore, each of the modules that together constitute a complex system has by itself become increasingly complex. Second, as the power of modularity comes to be widely recognized, firms have come to adapt themselves to new business environments that modularisation entails.

In a context that is most relevant to us, Baldwin and Clark (2000) give an operational definition of 'modularisation-in-design', examining the detailed process of designing an artifact. They define a design of an artifact to be a complete description of the artifact, which can be broken down into smaller units called design parameters. For example, a design of a mug cup has to completely specify such design parameters as materials, colors, height, weight, diameter of the vessel, whether it has cap or not, the diameter of the cap if it has a cap, and so on. Usually there are intricate interdependencies among those design parameters. In the above example, the diameter of a cap has to be specified only when the design designates the cup to have a cap (hierarchical dependency). When the mug cup has a cap, the diameter of the vessel and that of the cap have to be specified consistently with each other (lateral dependency). The whole of such dependencies is called a design structure.

A dependency between two design parameters implies that some coordination is necessary between those who determine the parameters. Thus, in general, a design structure with complicated dependencies will make the cost of coordination expensive. Therefore, it may pay to strive for the reduction in dependencies among design parameters. According to Baldwin and Clark, it is possible to eliminate intricate dependencies among several parameters by setting a 'design rule' that simultaneously determines those parameters. Carrying out this process repeatedly results in a modular design, in which there are relatively independent blocks. In each block, there remain intricate dependencies among design parameters. Across blocks, however, there are few, if any, dependencies. Thus each of these blocks may be regarded as a module.

Of course, the process of modularisation incurs costs. Baldwin and Clark illustrate this by the case study of IBM System/360, which they identify as the first platform with a modular design. In a word, it is very difficult to foresee and enumerate all dependencies ex ante. Thus, carrying out modularisation is a costly investment, which is sunk however, once a modular design is set. The modular structure of a product system can be reused across generations of designs of the product system. A platform or architecture is such an invariant property of the product system, which may be identified as a combination of modular structure and interfaces among modules. Under a fixed platform, successively new modular components are brought forth, resulting in generations of the product system.

As the above description of how to modularise a design suggests, the major purpose of modularising a design is to rationalize design processes of a complex product system so as to reduce coordination costs and to reuse the modular architecture over generations of products. This was certainly the case with IBM System/360. However, modularisation brings forth other benefits as well, to which I now turn.

4.2 Option Value

One may easily guess that modularisation brings forth the following benefits. First, modularisation enables the design tasks for modular parts to be conducted in parallel, i.e. concurrent engineering is made possible (Brooks 1995). Second, modularisation enables designers to concentrate on their own modular part without paying much attention to what's happening in different modular parts. In addition to these benefit, there can be the benefit of aggregating smaller improvements in respective modules, rather than adopting a new product system as a whole each time. One of the most important contributions to the theory of modularisation by Baldwin and Clark is that they pointed out and analyzed this benefit of modularisation by regarding the results of R&D activity as 'real options'.

Suppose that an organization is engaged in the R&D activity of the product system as a whole, the value of which is expressed by a stochastic variable X. Suppose that $X \sim N(0, \sigma^2)$, where zero is interpreted as the default value of currently existing product system. The expected value of the R&D activity in the current period may be lower as well as higher than the default value. However the result of the R&D activity in the current period will be adopted if and only if its value is higher than the default value. Thus the expected value of the product system at the end of the current period will be

$$E(X_+) = \int_0^\infty x\phi(x)dx = \frac{\sigma}{\sqrt{2\pi}},$$

where $X_+ = \max(0,X)$ and ϕ denotes the probability distribution function of $N(0, \sigma^2)$.

Next suppose that the product system is now divided into n modular parts, and at any moment before the adoption of the R&D result, the value of the whole system is the sum of the values of those modular parts.[9] Let the result of R&D activity in the i-th module be denoted by X^i and, to make the comparison easier, assume that $X^i \sim N(0, \sigma^2/n)$. That is, $X = X^1 + X^2 + \cdots + X^n$. Again, the result of R&D activity in each module will be adopted if

[9] One may think that this is too strong an assumption. However, in most cases, modularisation seems to allow the value of the whole product system to be expressed as the sum of the value of modular components. For a more detailed rationale for this assumption, see the next section.

and only if it is higher than the default value. The expected value of the i-th module at the end of the period is thus $E(X^i_+)$. Then it follows that for n > 1

$$E\left(X_+^1\right)+\cdots+E\left(X_+^n\right)=\frac{\sqrt{n}\sigma}{\sqrt{2\pi}}>E\left(X_+\right).$$

This implies that the expected value of a modularised product system is higher than that of a non-modularised product system. Observing that the left-hand side of the above inequality increases in proportion to the square root of n, it is easy to see that the finer the partitioning of a product system, the higher the expected value of the new product system. This is what Baldwin and Clark called the effect of the 'splitting operator'.

4.3 Coordination Costs Reduction

In Baldwin and Clark's account of modularisation, it was presumed that setting a design rule automatically eliminates interdependencies and thus reduces coordination costs. Then, in view of other benefit of modularisation, the finest possible partition would result in any modular design. However, this is hardly the case in reality. Thus, it becomes desirable to examine a more general, not necessarily modularised, setting and analyze what modularisation brings forth to a design organization.

The first attempt to extend the model of Baldwin and Clark in this line was initiated by Schaefer (1999). Schaefer identifies the benefit of partitioning a design organization as that of specialization (the second benefit in the previous subsection) unlike Baldwin and Clark. On the cost aspect, he assumes that the statistical correlations between the results of R&D activities for two design parameters become lower if these design tasks are allocated to different teams in a design organization. Thus as the partition becomes finer, the statistical correlations of R&D activities become lower, and the expected value of the whole product system will be lower, since the value function of the whole product system is assumed to be super-modular in the values of respective designs.[10]

On the other hand, Takizawa (2002) identifies the benefit of partitioning an organization as having many smaller real options following Baldwin and Clark, while cost of partitioning is thought of as arising from the increased incidence of across-team coordination under

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[10] If the value is expressed by a super-modular function, it is more beneficial to have all the variables move in the same direction, even if the move may be in a wrong direction. See Milgrom and Roberts (1994) for the argument.

finer partition. It is interesting that, although their models are different, both Schaefer (1999) and Takizawa (2002) give almost the same comparative static results. Here I will present the intuitions underlying my model.

Consider an organization engaged in the design of a product system. Suppose that the design of the product system is not necessarily modular, and so there may be intricate interdependencies among design parameters thereof. Given a design structure, consider the problem of partitioning the set of design parameters and allocating elements of the partition (subsets of the set of all the design parameters) to different teams. Suppose that there is dependency between two design parameters and some coordination is necessary between them. It would be natural to assume that the cost of coordination is higher when the two interdependent parameters are allocated to different teams than when they are worked out in the same team. Thus having a finer partition increases the incidence of across-team co-ordinations and the total coordination costs will increase. On the other hand, it is assumed that each team is a unit of decision-making as to the adoption of a new design. By this assumption, having a finer partition means having more number of smaller options, and is therefore beneficial.

By using the comparative static technique developed by Topkis (1998), I show that the optimal partition becomes finer if the cost of across-team coordination becomes lower, the cost of within-team coordination becomes higher, the degree of uncertainty in the results of R&D activity becomes higher. Those results are confirmation of the results obtained by Schaefer (1999). However, the paper provides further analysis by endogenizing the cost of across-team coordination. Intuitively, members in the same team will resort to face-to-face communication very frequently, perhaps because they are located closely. On the other hand, across-team coordination will require such communication devices as a facsimile, phone, or the Internet. Thus it would be natural to suppose that the design organization tries to lower the cost of across-team coordination by installing those communication devices with some costs. We can interpret that the choice of lower cost of across-team coordination by the organization corresponds to higher level of information and communications technology investment. The paper shows that higher cost of across-team coordination, lower within-team coordination cost, and coarser partition are complementary to one another in the design organization's objective function.[11] Therefore if the cost of within-team coordination is low, the organization will tend to rely more on within-team coordination and as a result, chooses coarser partition, which in turn leads to higher cost of across-team coordination, i.e. lower information and communication technology investment. Conversely, if the cost of within-team coordination is high, the organization will increase the information and communications technology investment and choose a finer partition.

Recall that this analysis deals with a very general design structure, and so does not presuppose the situation where the design of the product system is modularised in the sense of Baldwin and Clark. However, it also has some implication for the effect of modularisation in the sense of Baldwin and Clark on the design organization. Specifically, it can be shown in this model that modularisation in the sense of Baldwin and Clark sets an upper bound for the coarseness of the optimal partition. In this sense, modularisation works to make the partition of a design organization finer. Since finer partitioning is complementary to lower cost of across-team coordination, this implies that modularisation induces more information and communications technology investment.

Admittedly, the situation analysed in Schaefer (1999) and Takizawa (2002) is an optimisation problem faced by a single organization. However, we may interpret the problem as faced by a quasi-organization comprising multiple firms and each team in the model as an independent firm.[12] Then, the result of analysis can be interpreted as follows. Given the design structure of a product system, the size of each firm will be smaller if the cost of across-firm coordination cost becomes lower, the cost of within-firm coordination becomes higher, and the degree of uncertainty in development becomes higher. This prediction coincides with the result of the empirical analysis by Brynjolfsson, Maline, Gurbaxani, and Kambil (1994) that the information and communications technology investment has lead to smaller firm size in the US.

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[11] More precisely, the objective function is super-modular in those variables.

[12] Strictly speaking, interpreting each team in the model as an independent firm implies that the boundary of a firm is determined by the ease of coordination. Brynjolfsson, Maline, Gurbaxani, and Kambil (1994) explain this assertion by broadly interpreting coordination costs as 'transaction cost' in general.

This result is also instrumental to understanding the interesting comparison of industrial regions between Silicon Valley and Route 128 by Saxenian (1994). She observes that the Silicon Valley firms are marked by high mobility of workers, frequent communications and substantial degrees of information sharing among different firms, quite in contrast to the Route 128 firms. Thus it would be natural to think that the cost of across-firm coordination is substantially lower in Silicon Valley than in Route 128. Combined with the above analysis, this may explain why there are a lot of small independent firms in Silicon Valley, while large integrated firms are dominant in Route 128.

That higher cost of across-team coordination, lower cost of within-team coordination, and coarser partition are complementary to one another has another interesting implication. By adopting modular designs, the information and communications industries have been developing at an amazing pace possibly through the increased option values. This resulted in huge increases in the values of product systems in these industries as well as lower prices of information and communications technology investments, which in turn might have induced finer partition of product systems or smaller firm size in other industries.

4.4 Parallel Experiments

When the design of a product system is modularised over a quasi-organization and the interfaces among modular parts are made publicly open, it becomes possible that multiple firms are engaged in each modular product, competing with one another in its development race. Baldwin and Clark model this situation as the one where n(>1) independent stochastic trials are held in parallel for each modular product, and the result with the highest value, if it is higher than the default value, is adopted. The value created in this process is mathematically the expected value of the first order statistics of a sample with size n, and of course increasing in n. They call the value thus created the effect of ‘substituting operator’, showing that it can create a large value in combination with the ‘splitting operator’.

It seems more natural, however, to regard the above situation as the one where a set of tournament games are being held, in each of which firms engaged in the same modular component compete with one another. We will later introduce such a model.

5. Informational Arrangement for Modularity

Baldwin and Clark's argument for the power of modularity still leaves us with several questions. First, one may wonder how such an arrangement for product system innovation emerged and evolved in Silicon Valley. Baldwin and Clark identify IBM System/360 as the first conscious application of the concept of modularity, where three IBM engineers, Gene Amdahl, Gerrit Blaauw, and Fred Brooks, marshalled the whole process of modularisation. Although this process took time and incurred substantial costs, System/360 platform brought IBM an enormous success. Over generations of new products within the platform, IBM successfully retained control over how to improve the system. However, IBM eventually had to open the markets for its modular products, especially in the software and peripherals sector, because the antitrust policy of the U.S. government forced IBM to do so (Bresnahan 1999). Later in the case of the IBM-PC platform, IBM had even to concede their control over the platform to other companies like Intel and Microsoft. Thus, the mechanism is formed and reproduced by complicated interplays among several competing firms. I will later touch on it in the next section.

Second, although modularity-in-design defined by Baldwin and Clark is prima facie a technological matter, it should have a profound impact on economic institutions, especially on the organization of firms. This section explores such a question, especially from the information-systemic viewpoint. It is easy to see that modularisation of a product system can exert an impact on the way that information flows in the design organization; a modular design enables information flow in the design process to be hierarchical as well as encapsulated. Suppose there are two design parameters a and b that are interdependent on each other. Designers working on those design parameters will then have to mutually exchange information regarding shocks arising in their own tasks. However, if a design rule is set that determines both design tasks, it is possible to make an informational arrangement in which those designers only have access to the relevant design rule and they do not laterally exchange information.

What information-systemic arrangement is the fitest for the modular architecture of a product system? Aoki (2000) and Aoki and Takizawa (2002) analyzed this problem by using a team-theoretic framework à la Marschak and Radner (1972), in which all team members are assumed to have a common payoff function, i.e., the incentive problems are abstracted away. Suppose that a generic R&D organization, composed of a development manager denoted as M and two design teams denoted as T_i (i = a, b), is engaged in the development of a product system. M is engaged in formulating development strategy, the allocation of R&D funds and so forth, while T_i's are engaged in the R&D activities of respective components a and b. They coordinate their activities so as to maximize the value of the product system in uncertain environments. Suppose the activities they choose are aligned linearly. The activity levels of T_i's are interpreted as design attributes of the respective components. The environments affecting their activities are segmented as follows:

(1). A systemic segment E_s that affects the activities of all members (M and T_i's). Examples include the availability of total R&D funds and emergent industrial standards.

(2). Engineering segments that affect the activities of T_i's which are further divided into the following segments.

(2a). Engineering environment E_e that affects both T_i's. This may represent the uncertainty arising in the interface between the T_i's.

(2b). Idiosyncratic engineering environment E_i (i = a, b) that affect T_i's respectively.This may be exemplified by the technical difficulties particular to the respective tasks.

The members of the organization observe stochastic parameters arising in those environments with some error, and adjust their activity levels based on such observations. It would be easy to see that there can be various patterns of who observes what information and who share the observation.[13] Different patterns for information sharing generate different types of R&D organization, which exhibit different informational efficiency in different set of parameters. The types of R&D organization identified in Aoki (2000) and Aoki and Takizawa (2002) are as follows.

Hierarchical R&D organization

In this type of R&D organization, M is interpreted as an R&D manager of an integrated firm, while T_i's are project teams in the firm. Inserted between them is an intermediating agent, say a system engineer, denoted by IM. M is specialized in observing the stochastic

[13] However we assume that, in any mode of R&D organization, M is only engaged in the observation of E_s, and E_i's are only observed by T_i's.

parameter γ_s arising in E_s and transmitting the observation of γ_s, denoted ξ_s, to T_i's through IM. IM is engaged in observing the stochastic parameter γ_e arising in E_e, the observation of which ξ_e is communicated to T_i's. T_i's observe γ_i's arising in their own idiosyncratic engineering environments. The observation of γ_i is denoted by ξ_i. Thus M chooses his/her activity level based upon ξ_s, while T_i's choice variables depend upon $\xi_s + \varepsilon_{si}$, $\xi_e + \varepsilon_{ei}$, and ξ_i, where ε_{si} and ε_{ei} are the communication error on the side of T_i's. This type of R&D organization reflects the essential aspects of the R&D organization of a traditional, large hierarchical firm, sometimes referred to as the 'waterfall' model (Klein and Rosenberg 1986, Aoki and Rosenberg 1989).

Interactive R&D organization.

In this type of R&D organization, M is interpreted as an R&D manager, while T_i's are interactive development teams. All of them share the information regarding the systemic environment through interaction and communication. T_i's also share information regarding the systemic engineering environment, while they observe the stochastic parameter γ_i arising in their idiosyncratic environment independently. Thus M's activity level depends upon ξ_s (common to M and T_i's), while T_i's depends upon ξ_s, ξ_e (common to T_i's), and ξ_i (idiosyncratic to T_i). The characteristic of this type of R&D organization is that assimilation of information is realized through the feedback of information across the levels of the organization as well as the teams on the same level. This type of R&D organization is sometimes referred to as 'chain-linked' model of innovation (Klein and Rosenberg 1986, Aoki and Rosenberg 1989).

V-mediated information encapsulation

In this type of R&D organization, information regarding the systemic environment is shared among M and T_i's as in the interactive R&D organization. However, unlike it, T_i's are engaged in the observation of the systemic engineering environment and idiosyncratic engineering environment independently. Thus M chooses his/her activity level depending upon ξ_s, while T_i's activity level depends upon ξ_s (common to M and T_i's) and ξ_e (idiosyncratic to T_i) and ξ_i (idiosyncratic to T_i). There can be two kinds of interpretation for this type of R&D organization. On the one hand, it can be interpreted as a highly autonomous project teams within an integrated firm. On the other hand, it can be interpreted as reflecting the unique mixture of decentralized information sharing and information encapsulation observed in the relationship between venture capitalists and entrepreneurs in Silicon Valley.

The objective function of the R&D organization comprises not only the stochastic parameters as listed above, but also constant parameters that are related to the degree of complementarity among activity levels of the members.[14] Suppose that, once the R&D organization chooses the type of organization, the members thereof coordinate their activity levels according to the second-best decision rules. Then different types of R&D organization are shown to be optimal in different sets of stochastic parameters and constant parameters. Within this framework, Aoki (2000) and Aoki and Takizawa (2002) show that, among the three types of R&D organization, the V-mediated information encapsulation is the most efficient type, if the idiosyncratic engineering environment is important (its variance is large) relative to the systemic engineering environment, and/or the attribute complementarity between both project teams is low. This proposition has the following implications in the present context.

First, modularisation partitions a complex product system into multiple modules so that the modules are relatively independent. Thus, the way of partitioning cannot be arbitrary at all. Albeit in a somewhat different context, Crémer (1980) shows that an organization is optimally partitioned when the statistical correlations among the units created by the partitioning are minimized. This means, in the current context, that the whole design task should be divided into two tasks so that the systemic engineering environment is unimportant relatively to the idiosyncratic engineering environment. Thus the viability of the V-mediated information encapsulation as observed in Silicon Valley is enhanced by 'good' modular architecture of a product system. Second, all the modules created through

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14 The objective function common to all the members can be expressed as a following quadratic function

$$V(x, y_a, y_b) = \gamma_s x + (\gamma_s + \gamma_e + \gamma_a) y_a + (\gamma_s + \gamma_e + \gamma_b) y_b$$
$$- \frac{A}{2}x^2 + Dx(y_a + y_b) - \frac{K}{2}(y_a + y_b)^2 - \frac{L}{2}(y_a - y_b)^2,$$

where x is M's choice variable, y_i's are T_i's choice variables (i = a, b). As we noted in the text, this objective function has two kinds of parameters. On the one hand there are stochastic parameters. γ_s is a parameter exhibiting the uncertainty arising in E_s, γ_e is a parameter indicating the uncertainty arising in E_e, while γ_i's are parameters showing the uncertainty arising in E_i's. On the other hand, K and L are constant parameters. $\partial^2 V/\partial y_a \partial y_b = L - K$ exhibits the degree of complementarity between the activity levels of T_i's. Namely, they are complementarity if K < L, while they are substitutes if K > L. We assume that the activity levels of M and T_i are complementary so that $\partial^2 V/\partial x \partial y_i = D > 0$ holds.

the process of partitioning have to be compatible with one another and work together in a smooth manner. In order to assure such compatibility, the interfaces among those modules have to be clearly and explicitly determined in the process of modularisation. Thus modularisation enables R&D activities for respective modules to be conducted in parallel and to be later combined. This means that modularisation reduces the technological complementarity between the two teams, which will generally exhibit some degree of complementarity. Therefore the standardization of interfaces also makes the V-mediated information encapsulation a viable organizational arrangement.

On the other hand, as the complementarity between the two tasks is reduced, the value function will be almost additively separable, meaning that the improvement of the whole product system stems from that of each modular product, rather than from the coordinated and simultaneous improvements of several modular products. This sets the technological basis for a product system to be formed evolutionarily by combining new modular products ex post. Thus the two aspects of modular architecture—partitioning of a product system and standardization of interfaces—are complementary to the mixture of decentralized information sharing and information encapsulation, which we think is the unique organizational arrangement observed in Silicon Valley.

This observation is also helpful in understanding why most success stories in Silicon Valley are concentrated in the information and communications industries. In fact, the technological development in the information and communications industry has been fostered by setting standards for various interfaces that arise in the information and communication systems: IBM's System/360, IBM-PC compatibles, the Internet, and so forth. Once good architecture is set, innovations usually take place in individual modules, and architecture and interfaces will change less frequently. In such an environment, complementarity between modular products and/or the degree of uncertainty in the systemic engineering environment will be reduced, which would make V-mediated information encapsulation more viable as an organizational arrangement.

The above argument also sets a general framework for understanding what's happening in the automobile industry. In general, the design of automobiles is said to exhibit a strong complementarity between various task units. Thus, the interactive R&D organization will be the most efficient type of R&D organization, as often observed in Japanese automobile companies. Indeed, many management scientists have reported that the design/production processes of automobiles necessarily require "*suriawase* (tight coordination)" across various task units (Fujimoto 1997). However, the present landscape of automobile industry around the world looks somewhat intricate: while Japanese automobile companies are reluctant to adopt general-purpose modular parts, European and American counterparts are opting for outsourcing modular parts. This may be the evidence that technology is determined rather endogenously by the organizational conventions in each country's economic system. The above model assumes that technology determines the information system of R&D organization, but the different kinds of information-processing activities in different information systems may require corresponding skills. Thus the current distribution of relevant skills in a country may affect the adoption of technology.

6. Modularisation and Incentives

Section 2 examined how a venture capital contract is structured to motivate an entrepreneur, who is not necessarily in a modular environment. Modularisation of a product system adds a new dimension to the entrepreneur's incentives to innovate however. I have so far deferred incentive effect of modularisation, so that the pie to be shared has been fixed. However, one of the most striking natures of modularisation may be in its impact on incentives to innovate, to which we now turn.

6.1 Open interfaces and competition

A modular design can creat a new industrial arrangement where multiple firms are independently engaged in the development of the same modular part of a product system—the phenomenon observed among entrepreneurial firms in Silicon Valley. As the example of IBM System/360 illustrates, the standardization of interfaces among modules is not sufficient for the entrance of new firms into the development of modules. The interfaces have to be somehow made publicly 'open'.

In Section 4.4, we have already seen how Baldwin and Clark's substituting operator essentially captures the value-enhancing aspect of such an arrangement. However, their model abstracts away the incentive issues, which may be important in this situation. Formulating this situation as a 'VC tournament game', Aoki (2001) explicitly considers the incentive effect of this mechanism on the participants for the case where the number of participants is two. Since only one of the two participants can be the tournament winner, this mechanism necessarily entails social costs of the duplication of R&D activities. Aoki shows that this mechanism can create more value than the social cost nonetheless, because it can entice very high efforts from the participants if the prize for the winner is sufficiently large and the competence of venture capitalists to precisely determine the winner is sufficiently high.

In Silicon Valley, the winning entrepreneurs can expect to obtain a huge amount of prize as the founder's benefit, because successful entrepreneurial firms will either go to the IPO markets or will be acquired by a leading firm. Furthermore venture capitalists are specialized in relatively small technical segments and very capable of evaluating a new technology. These facts suggest that entrepreneurs have enough incentives to participate in the tournament game held in Silicon Valley and that the mechanism may be socially efficient. Aoki's analysis also provides us with an important insight that the existence of competent venture capitalists is the key to the success if one wants to transplant the mechanism for product system innovation à la Silicon Valley into other regions and/or industries.

Aoki and Takizawa (2002) extended the Aoki model by endogenizing the number of tournament participants as a choice variable of a venture capitalist. Their model can also be seen as an extension of Baldwin and Clark's model of substituting operator in the sense that it also captures the benefit of having multiple experiments in the same modular product. The obtained results are as follows:

(1) An increase in the number of tournament participants will lower the incentives for each participant in equilibrium. On the other hand, with their effort levels given, the more the number of participants is, the more is the value created. Thus, the optimal number of participants is determined by the trade-off between these two countervailing factors.

(2) An increase in the marketing uncertainty will decrease the equilibrium effort level and thus the expected value of the project, while an increase in the technical

uncertainty increases the equilibrium effort level and the expected value of the project.[15]

(3) A decrease in the cost of start-up financing necessary for each project will increase the optimal number of tournament participants.

The above propositions have some interesting implications for the dot.com bubble in which most entrepreneurial firms are engaged in the so-called e-commerce businesses. Although the dot.com bubble and crash might have been caused primarily by the erroneous expectations regarding profitability (Baldwin and Clark 2001), the above observation indicates that the number of entrants into the Internet/Web services was very large, because their start-up costs were low. The above observation suggests that a large number of entrants might have adversely affected the incentives of entrepreneurs. Furthermore it is often said that the technology involved in these businesses was not strikingly innovative, and only new business models had to be contrived. Indeed, most of the basic technologies used by e-commerce businesses and the Internet auction have long been known in experimental economics. Thus most e-commerce businesses had low technological uncertainty as well as high marketing uncertainty, which might also affected the entrepreneurs' incentives and thus the expected value of the projects adversely.

6.2 Ex Post Evolutionary Formation of a Product System and the Role of Innovation Commons

It is a well-known fact that IBM, who successfully had retained the controlling position of System/360, had to concede its position of controlling the PC platform to Intel and Microsoft, which resulted in the so-called 'Wintel' platform. Thus, as a, hitherto dominant, single firm loses the exclusive control over the direction of innovation, another possibility emerges in the innovation of a modularised product system. A modularised product system can now continually evolve in a fairly complex manner. Firms that aim to assume leadership try to change the product system by proposing their own interfaces, out of

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[15] According to the observation by an experienced venture capitalist, the marketing uncertainty tends to be low (high) when the technological uncertainty is high (low). Investment in Silicon Valley used to be concentrated in the projects with high technological uncertainty and low marketing uncertainty. However the trend has been reversed recently due to an increase in the number of entrepreneurial firms engaged in the e-commerce. Venture capitalists, of course, have to consider different properties of the risks to build their portfolio. See Lee, Miller, Hancok, and Rowen (2000).

which *the* interface is evolutionarily formed. Aoki coined the term 'ex post evolutionary formation of a product system' (Aoki 2001) to express an aspect of this complicated process, which is almost equivalent to what Bresnahan (1999) calls 'divided technological leadership' or 'vertical competition'.

Baldwin and Clark identify the following modular operators, which can be applied to various points of a given product system (Baldwin and Clark 2000:228):[16]

(1) splitting a module further into multiple modules;
(2) substituting a module for another;
(3) augmenting the system by adding a module with new functions at a particular interface;
(4) excluding a module from the system;
(5) inverting a recurrent design element in several modules into an independent module;
(6) porting a module to another system.

It should be emphasized that a single firm no longer controls the whole process of innovation. The complication of a product system often involves a fierce competition for technological leadership, which often involves creation of new products that rebundle several modular components. Modular architecture of a product system now ceases to be a well-defined static partitioning of the design tasks and turns into a fertile ground on which the product system continues to evolve, the process of which might gradually change the original architecture.

The elucidation of the dynamics of such an evolutionary process necessarily requires a synthesis of research results developed here and elsewhere. Christensen, Verlinden and Westerman (2002) recently attempt to provide a grand theory of industrial dynamics based on the concept of modularity. They assert that the causal driver for integration/disintegration is whether customers are under- or over-served by the functionality of products. In tiers of the market where customers are over-served by the functionality available from products in the market, speed to market and the ability to

[16] The list of modular operators here includes 'splitting' and 'substituting' operators already explained. Note that these operators can be applied to modular parts of an existing product system.

conveniently customize the features and functions of products to the specific needs of customers become a critical dimension of competition, which force firms in the market to adopt a modular design. In contrast, in tiers of the market where customers are under-served by the functionality available from products in the market, the competitive advantage from vertical integration will be strong. Usually the speed of performance improvement that the innovators in an industry provide to their market is higher than the speed of performance improvement that customers can actually absorb or utilillize. Thus, an industry in which customers are under-served by the functionality can eventually turn into the one in which they are over-served by the functionality. Correspondingly, the industrial organization will swing between integration and stratification. While Christensen, Verlinden and Westerman (2002) provide empirical results roughly supporting their hypothesis, details remain to be elaborated.

In the dynamic evolution of a product system, the institutional arrangement for intellectual property rights can be critical. As I have argued, modularisation is conductive to open architecture or open interfaces. However, the openness of architecture or an interface per se does not necessarily assures the existence of an innovation commons, because the firm with a patent over the current technology may file a lawsuit against others with the intention to prevent them from changing the technology. It should be noted, however, that when generations of new products are created ex post by combining modular components in a modular architecture, the current architecture of the product system can be said to be playing the role of 'innovation commons', where the opportunity to innovate and build upon the current platform is kept open to anyone (Lessig 2002).

Lessig argues that any process of innovation can be regarded as a production function that produces a new idea with old ideas and innovator's human capital being inputs. This perspective illuminates that there are two countervailing powers acting on innovators' incentives. On the one hand, protection of intellectual property rights enhances innovators' incentives, since it enable him/her to reap a reward. On the other hand, however, making the intellectual property rights too stringent can hurt new innovators' incentives, because it makes it too costly to try a new idea. Thus, striking a right balance between these two factors is especially important. While making some resources freely accessible may seem to hurt innovators' incentives, there can be various ways to reap what he/she sowed. Lessig's point is best illustrated by the Internet and IBM-PC compatibles, where various technologies flourished on the innovation commons. The existence of an innovation commons can, and actually did, invite more new innovators to innovate, which results in a rapid technological development as well as increased uncertainty regarding the direction of innovation.

It may be just a historical process that made IBM-PC architecture an innovation commons. In some cases, however, abandoning a proprietary strategy may enable an innovator to earn a higher profit, because the pie to be shared will be huge if his/her technology was successful in assuming the position of de facto standard and in meeting comsumers' needs (Kokuryo 1999). Thus, strengthening intellectual property rights is not the only way to incentivize innovators. Furthermore, we should keep in mind that the current information and communications technologies flourished because AT&T did not control how its wires were used due to the government restriction of the control. Although still many issues remain to be resolved, the commons argument tells us that fine-tuning various rights, as in a compulsory lisence arrangement, may enhance social efficiency, instead of simply strengthening intellectual property rights.

7. Conclusion

This paper has examined the new arrangement of product system innovation that has emerged in Silicon Valley with the main focus on two aspects: complex venture capital contracts that structure governance of entrepreneurial firms, and modular architecture of product systems. On the one hand, I argue that complex allocation of various rights is utilized in venture capital contracts, which is beyond the perspective of the traditional property rights framework. On the other, the recent outstanding development of information and communications industries became feasible largely thanks to the adoption of modular designs for various product systems in the industry. Modularisation incredibly increased the productivity of R&D efforts. Modularisation created a new industrial structure where clusters of small firms are engaged in developing modular products. Modularisation has opened the doorway to ex post evolutionary formation of a product system, often contributing to creating a new product market. In one word, modularisation has changed the way that we do businesses wherever a product system can be modularised.

Admittedly, this paper is mainly concerned with information and communications industry. Nontheless, arguments made can be relevant to developing countries. First, since the situation in which a wealth-constrained entrepreneur seeks funding for his/her project idea is ubiquitous, the analysis of real-world venture capital contracting provides a basis for devising institutional environments in the developing countries as well. Second, an increasing number of developing countries are now involved in the production of modular products. For example, most of the production of hard disk drives has already been transferred to South-Eastern Asia by the late 1990s, although almost all the design process is still retained in Silicon Valley. The transfer of knowledge would come along with this shift of production, and knowing the nature of modular environments can be very important. Third, as I argued in Section 6, increased knowledge of the nature of the product system innovation in Silicon Valley is now inviting a serious interest in the role of patent/copyright system in innovation. It has come to be widely recognised that, while incumbent firms loby for strengthening the current intellectual property rights, it can hurt new innovators' incentives to innovate. Although many still remain to be debated, it seems that, when it comes to ideas, the allocation and perfect enforcement of exclusive property rights over them may not necessarily assure efficiency of an economic system.

Information and communications industry is still changing so rapidly that it is extremely difficult to extract the essentially novel part of the observed arrangements. In this sense, this paper is just a cornerstone for illuminating some aspects of the emergent arrangement in the new industry. Of course, there remain a lot of issues waiting to be explored. Two of the most imminent research issues are to advance comparative industrial studies of modularisation, and to explore further the applicability of modularisation beyond information and communications industry. Theoretical studies on property rights also seem promising. As the analyses of venture capital contracts and the argument for innovation commons suggest, property rights are after all a bundle of various rights, allocation of which can be more freely designed.

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