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Understanding the Silicon Valley Phenomena

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Abstract

This paper analyzes the 'Silicon Valley model' as a novel economic institution in the domain of technological product system innovation such as computers. We focus on the information structural relationship as well as governance relationships between venture capitalists and a cluster of entrepreneurial firms. The informational conditions under which the Silicon Valley model is efficient are identified, leading to understanding the significance of standardization of interfaces, modularization and information encapsulation. We then examine the governance/incentive aspect of the model by integrating the models by Aoki, and Baldwin and Clark to give comparative statics results regarding the optimal number of entrepreneurial firms competing in the same component product. The analyses enable us to evaluate the applicability of the model beyond specific localities and industries.

Keywords: Silicon Valley, innovation enterprises, tournament games

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1 Introduction

In the aftermath of the so-called dot.com bubble and crash, previous enthusiasm for the Silicon Valley phenomena seems to have faded away. The fact still remains to be elucidated, however, that Silicon Valley has been successful in bringing so many outstanding entrepreneurial firms into the world. What mechanism made Silicon Valley a major driving force for product system innovation, especially in the computer industry? Can it be transplanted into a wide variety of local and industrial domains beyond Silicon Valley? The purpose of this paper is to analyze such Silicon Valley phenomena as a novel economic institution in the domain of technological product system innovation.

The most conspicuous example of the Silicon Valley phenomena can be found in the computer industry. As is documented by Baldwin and Clark (2000), the computer industry was virtually a monopoly market dominated by IBM for a long time until 1970. However, a bunch of entrepreneurial firms, mostly small and funded by venture capitalists, have been set up since 1970's and been very agile in R&D activities. The apparent feature common to these entrepreneurial firms is that they usually develop and produce modular parts of a product system, rather than compete with IBM by producing a standalone product system. Many new sub-industries have been thus formed within the domain of the traditional computer industry, and a variety of R&D activities traditionally conducted within IBM are now conducted independently outside. This process has drastically changed the landscape of the computer industry. A new product system is now evolutionarily formed by selecting and combining *ex post* new modular 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. We will henceforth call such a system of product system innovation the "Silicon Valley Model" (Aoki 2001).

At first sight, it might appear that the property rights theory, as developed by Grossman and Hart (1986) and Hart and Moore (1990), can be applied to explain why R&D activities previously conducted within sections of an established integrated firm have come to be conducted independently by small entrepreneurial firms. However, it is not easy for this approach to explain the unique manner of processing information, which is prevalently observed in Silicon Valley. Indeed, as Saxenian (1994) points out, in Silicon Valley there is a substantial degree of information sharing across competing entrepreneurial firms on the one hand, and information hiding (encapsulation) on the other. Understanding these ostensibly contradictory phenomena is the key to understanding the Silicon Valley model.[2]

Baldwin and Clark (2000) is an attempt to understand the Silicon Valley model by focusing on how information is processed in the design of a product system. They submit that the “modular design” of complex system like a computer is the key concept for understanding the emergence of a large modular cluster of firms and markets in the computer industry. While their explanation of the power of modularity is persuasive, they do not explicitly analyze the incentive aspects of the Silicon Valley model. We submit that it is not sufficient to analyze the Silicon Valley model only from the information systemic aspects, or only from the governance aspects. We extend their model of “substitution operator” by explicitly considering the incentive of each entrepreneur.

The Silicon Valley phenomena contain multifaceted interaction between a cluster of entrepreneurial start-up firms on the one hand, and venture capitalists (as well as leading firms in respective niche markets) on the other. In order to properly capture the essential nature of this model, it is necessary to identify unique roles played by those actors. Section 2 offers our modeling background by describing stylized facts about their relationships. We submit that that it is not sufficient to look only at the property right relationship between a venture capitalist and a single entrepreneurial firm, and that the venture capitalists usually have dual roles in their relationship with entrepreneurial firms; the role as a mediator of information and the role of structuring governance. In Section 3, we develop a team-theoretic model that is meant to capture the information-processing activities of venture capitalists and entrepreneurial firms in the course of R&D activities, and thus examine the significance of standardization of interfaces, modularization, and information encapsulation for the Silicon Valley model. Section 4 formulates the relationship between a venture capitalist and entrepreneurial firms as “VC tournament game” and analyze the governance role played by venture capitalists. We extend the model in Aoki (2001) by endogenizing the number of entrepreneurial firms competing in the same component product. It can also be regarded as a natural extension of the model of Baldwin and Clark (2000), in which the developmental effort level by each entrepreneurial firm is an exogenous variable. By this integrated model, we show how the effectiveness of their powerful “substitution operator” is limited by incentive consideration. Section 5 concludes the paper by evaluating the applicability of the Silicon Valley model beyond specific localities and industries.

2 Stylized Facts as Modeling Backgrounds

From a purely financial viewpoint, venture capital funds is an intermediary that serves to intermediate in the supply of a large sum of investment funds from other financial intermediaries. In legal terms, the venture capital process is unique in that it is a system of partnership, in which there are two classes of partners; general and limited. The general partners, acting as organizers of the fund, accept full personal responsibility and legal liability for fund management, while the limited partners supply most of the capital, but are not involved in the management and investment decisions of venture capital funds, which allows them to enjoy limited liability status as well as the advantage of avoiding double taxation. Funds are usually maintained only for a fixed period of time. However, in many cases, management companies are formed and run by general partners to provide management continuity. In this paper, we do not explicitly differentiate between venture capital funds and venture capital companies and refer to both simply as venture capitalists.

Venture capitalists seek promising investment projects, while potential entrepreneurs with planned projects but insufficient funds seek venture capital financing. There are more than 200 venture capital companies in Silicon Valley, and experienced venture capitalists are said to receive over 1,000 application per year. Suppose that a promising match is found. Unless the reputation of an entrepreneur is already known to venture capitalists and the proposed project is judged to be certainly sound and promising, the venture capitalist initially provides only seed money to see if the entrepreneur is capable of initiating the project, while possibly extending aid to help the start-up. When a venture capitalist decides to finance a start-up, elaborate financing and employment agreements are drawn up between the venture capitalist and the entrepreneur. Usually, start-up financing involves consortium financing by several venture capitalists, with one of them acting as a lead financier and the position of lead manager is rotated over different projects. This arrangement serves as a mechanism of reciprocal delegation of monitoring among a group of venture capitalists. The reciprocal delegation not only avoids the duplication of intense monitoring, but also functions as a device to control possible shirking of monitoring by venture capitalists (Lerner 1994, Fenn, Liang, and Prowse 1995). We will abstract from this reciprocal relationship among venture capitalists, and look at the relationship of entrepreneurial firms with venture capital funds as if there were a single venture capitalist.

At the time of start-up, the venture capitalist commits only a fraction of capital needed to complete the project, with the expectation that additional financing will be made stepwise, contingent upon the smooth proceeding of the project, which may not be contractible. This is a process that Sahlman (1990) called “staged” capital commitment. Financing by venture capitalists normally takes the form of convertible preferred stocks or subordinate debt with convertible privileges (Fenn, Liang, and Prowse 1995, Gompers and Lerner 1996). This means that they are paid prior to holders of common stock in the event of project failure. Also they retain an exit option exercisable by refusing additional financing at a critical moment when a start-up firm needs infusion of new funds to survive. However, a typical share holding agreement allows an entrepreneur to increase his/her ownership share (normally in common stock) at the expense of investors, if certain performance objectives are met. Fired entrepreneurs forfeit their claims on stock that has not vested.

There are many business failures among entrepreneurial start-up firms. Many failures crop up early, usually in the first one or two years. Frequent failures may be caused not only by overzealous competition among ambitious entrepreneurs, but also the venture capitalist itself may contribute to this. William Sahlman and Howard Stevenson observed the following phenomenon in an emerging segment of the computer data storage industry in the mid-1980's. "In all, 43 start-ups were funded in an industry segment that could be expected in the long run to support perhaps four. Thus "failure" is at the very least endemic to the venture capital process, an expected commonplace event; in some cases, the process itself may even promote failure" (Gorman and Sahlman 1989, p.238). In casual conversations in Silicon Valley, venture capitalists normally regard 3 successes out of 10 initial fundings as reasonable.

Venture capitalists are well represented on the board of directors of the start-up firms. In addition to attending board meetings, lead venture capitalists often visit entrepreneurs *cum* senior managers at the site of venture-funded firms. They provide a wide range of advice and consulting services to senior management; helping to raise additional funds; reviewing and assisting with strategic planning; recruiting financial and human resource management; introducing potential customers and suppliers; providing public relations and legal specialists. They also actively exercise conventional roles in the governance of the start-up firms, often firing the founder-managers when needed.

If the project is successful, the relational financing terminates either with initial public offering (IPO) or with acquisitions by other firms. Capital gains are distributed between the venture funds and the entrepreneur according to their shares at that time. Before the dot.com bubble, it usually took five to seven years for start-up firms to go to the IPO market. During the dot.com boom, this period was shortened, especially for e-commerce businesses. This is because the technology involved was not strikingly innovative in those businesses, but only new business models had to be contrived. For example, basic analytical algorithms of internet auction sites have been long-known in experimental economics. On the other hand, in the biotechnology industry where R&D uncertainty is still relatively high, the shortening of the period needed for the recovery of venture-capital investment returns has not been as dramatic. Anyway, after the crash, the time period seems to have got back to that observed before the dot.com bubble.

Recently successful start-up firms have the tendency to become targets of acquisition by leading firms in the same market rather than going to IPO markets. From the viewpoint of start-up entrepreneurs, they are said to prefer buy-outs to IPO's, particularly when they have only a single innovative product line (Hellmann 1998). These leading firms are often themselves grown-up entrepreneurial firms that have been successful in assuming leadership in setting standards in their niche markets. They aim to acquire successful start-up firms, either to kill off potential challenges to the standards they set, or to further strengthen their market positions by shortening the period of in-house R&D by the so-called A&D (acquisition and development). They also seek to establish a monopolistic position in the market by bundling complementary technologies. In so doing, these leading firms have an great influence on venture capitalists, and thus entrepreneurial firms, in guiding their activities. This mechanism as a whole enables a new technological product system to be formed evolutionarily by combining flexibly new modular products *ex post*.

For the above described mechanism to work, it is necessary that the standardized interfaces are prescribed among different modular products and that information processing activities are encapsulated and/or hidden within each entrepreneurial firm in the course of developing respective modular product. This is a unique mechanism of information sharing/hiding that Saxenian (1994) found to be the key to the innovative nature of Silicon Valley firms. Standardization of interfaces is as much a product of architectures defined by dominant firms (especially Intel and Microsoft in the current era) and of industry standard-setting organizations such as Semiconductor Equipment and Materials International (SEMI) and the Internet Engineering Task Force (IETF) as of coordination by venture capitalists. Similarly, firms like Sun are competing with products like Jini and Java to define the interface standards for emerging markets. Even the leading positions of established firms in respective niche markets may not be secure in highly uncertain and competitive technological and market environments. Rather standards may be conceived to be evolutionarily formed and modified through the interaction of firms, large and small. In this process, venture capitalists also play an important role in intermediating necessary information among these actors, especially entrepreneurial firms.

By now the reader should notice that the venture capitalists play a wide range of roles vis-a-vis entrepreneurial firms; *ex ante* monitoring (screening of proposed projects to cope with the possible adverse selection problem); *ad interim* monitoring; *ex post* monitoring (the verification of project results and the controlling decision as to which exit strategy is to be exercised); mediation of information regarding standardization of interfaces. These functions are of course not fulfilled exclusively by a single venture capitalist. *Ex ante* and *interim* monitoring requires professional engineering competence in specialized fields, while *ex post* monitoring requires financial expertise. Thus the venture capitalists tend to focus on companies in specific industries to meet such needs. However we abstract from such complication in the real world and assume that a single venture capitalist fulfills those functions.

During the so-called dot.com bubble, many start-up entrepreneurial firms were set up under the above described mechanism, but most of them lost money only to disappear. Those events might lead one to doubting the viability of the Silicon Valley model. However it should be stressed that the model had been effective even before the dot.com bubble, and the crash just got things back to normality. The cause of the bubble may be attributed to the lack of rational expectation on the side of investors regarding the value to be realized (Baldwin and Clark 2001). The mechanism as such still remains effective for creating value and deserves to be examined.

In summary, a venture capitalist may be regarded as playing dual roles in the Silicon Valley model; intermediating information in the process of standard setting, selecting and combining modular products *ex post*; governance role in the entrepreneurial firms. Section 3 deals with the information structural aspect, while Sections 4 analyzes the governance aspect.

3 Information Systemic Aspect of the Silicon Valley Model

3.1 Comparative R&D Organizations

The previous section suggested that one of the major roles of venture capitalists lies in the mediation of information in the process of setting standards, and the formation of a new product system by selecting and combining modular products *ex post*. It would be natural to ask under what conditions such a unique arrangement of R&D activities can be superior to the traditional R&D organizations in a large integrated firm.

Suppose that a new technological product system is created by combining module component products. For example, a laptop computer as a technological product system consists of such component elements as LC monitor, MPU, image-processing LSI, hard disk drive, OS, application software, audio and communication devices, etc. In general, there are complicated dependencies among design tasks of those component products. Therefore, developing such a complex product system as a laptop computer requires continual coordination among design tasks of different component products so that they may fit with one another to form a coherent product system.[3] The volume of information exchanged and processed among those design task units can be so huge that any single agent will not be able to marshal the whole process in a centralized manner. Since each human being is boundedly rational in his/her information processing activity, we usually form an organization to transcend human limitation partially, and attempt to solve the problem by installing a structured information processing system.

In order to capture such structured information processing activities, suppose that a generic R&D organization is composed of a development manager denoted by M, and two product design teams denoted by $T_i (i = a, b)$. M is engaged in such tasks as development strategy, the allocation of R&D funds, and so forth, while the product design teams are engaged in the design of products, each of which is to constitute a component (say, a monitor, a hard drive, etc.) of an integral technological system (say, a laptop computer). They coordinate their activities so as to maximize the value of the product system in uncertain environments, which are assumed to be segmented as follows. There is a systemic segment, E_s, say the availability of total R&D funds, emergent industrial standards, that simultaneously affects the organizational returns to decision choices by M as well as T_i's (systemic environment, hereafter). Next, there are the segments of environments that affect the organizational returns to decision choices by T_i's, engineering environments, which can be further divided into three subsets: E_e, common to both teams (systemic engineering environment, hereafter), and E_a and E_b, idiosyncratic to respective projects of the teams (idiosyncratic engineering environment, hereafter). In what follows, we assume that M is engaged in observing E_s, and E_a and E_b are only observable by T_a and T_b respectively. The possible ways in which other aspects of information processing is specified will characterize each mode of R&D organization.

Assuming that activities of each member is aligned linearly, the above described situation can be formulated by using a team-theoretic model developed by Marschak and Radner (1972). Suppose that the value of the technological product system, which is also the payoff common to all the members, is expressed as[4]

$$\begin{aligned} V(x, y_a, y_b) &= \gamma_s x + (\gamma_s + \gamma_e + \gamma_a) y_a + (\gamma_s + \gamma_e + \gamma_b) y_b \\ &\quad - \frac{A}{2} x^2 + D x (y_a + y_b) - \frac{K}{2} (y_a + y_b)^2 - \frac{L}{2} (y_a - y_b)^2 \end{aligned}$$

where x is the choice variable by M, y_i's are choice variables by T_i's$(i = a, b)$. There are two kinds of parameters in this payoff function; stochastic parameters and constant parameters. γ_s,γ_e,γ_a,and γ_b are stochastic parameters expressing uncertainty arising in environment E_s,E_e,E_a,and E_b respectively. Observe that γ_s affects the returns to x as well as y_i's, and γ_e affects those to y_i's, while $\gamma_i (i = a, b)$ affects only y_i. Constant parameters are K,L,A,D. Note that because $\partial^2 V / \partial y_a \partial y_b = L - K$ measures the degree of technological and/or design attribute complementarity, the choice variables of T_i's are complementary when $K > L$, and substitute when $K < L$. It would be natural to assume that the choice variables of M and T_i's are complementary (namely $\partial^2 V / \partial x \partial y_i = D > 0$). The value function is assumed to be strictly concave. Under the above assumptions, the sufficient conditions for the value function to be strictly concave in (x, y_a, y_b) is $A >$

$0, K + L > 0, AK - D^2 > 0$.[5] Further we assume $K, L > 0$ without loss of generality, because any value of positive $K+L$ and $K-L$ can be produced by appropriately selecting positive K and L.

As already stated, we assume that M is engaged in observing E_s, and E_i's are observed only by T_i's$(i = a, b)$. Other specification about observation and/or information sharing via communication will characterize each type of R&D organization. In the sense that any agent cannot observe all environmental variables, and thus has to base his/her decision on only partial information, this is a second-best situation. Also assume that all the agents observe environmental variables with some error due to bounded rationality. In this team-theoretic setting, at first, each type of R&D organization decides how to share various information among M and T_i's, although complete information sharing is impossible as stated above. Given such information structure, it then adopts a second-best decision rules to maximize the expected payoff. A decision rule maps pieces of available information to choice variables. We are interested in what type of R&D organization can most successfully coordinate agents' choice variables under specific environments. A type of R&D organization is defined to be *informationally more efficient* than another if the maximized expected payoff to it is greater than that to another, which means that a type of R&D organization is superior to the other type as a coordination system in given environments.

We further assume that all environmental shocks are normally distributed with mean zero. The observation errors when M and T_i's observe E_s,E_e,E_a,and E_b are denoted by ϵ_s, ϵ_e, and $\epsilon_i (i = a, b)$. They are also assumed to be normally distributed with zero mean. They are all independent. Thus

$$\gamma_s \sim N(0, \sigma^2_{\gamma_s}) \quad \gamma_e \sim N(0, \sigma^2_{\gamma_e}) \quad \gamma_i \sim N(0, \sigma^2_i)(i = a, b)$$

and

$$\epsilon_s \sim N(0, \sigma^2_{\epsilon_s}) \quad \epsilon_e \sim N(0, \sigma^2_{\epsilon_e}) \quad \epsilon_i \sim N(0, \sigma^2_{\epsilon i})(i = a, b)$$

Other errors due to communication process or distinctive of each type of organization will be defined when it is necessary.

(1) Hierarchical R&D Organization In this type of R&D organization, M is the research manager of an integrated firm and T_i's are its internal project teams. Between them is an intermediate agent IM, say a system engineer, inserted. M is specialized in monitoring E_s. Let us denote M's observation by $\xi_s = \gamma_s + \epsilon_s$, which is communicated to IM. IM is engaged in monitoring E_e and communicating M's and his/her observation to T_i's. We denote IM's observation by $\xi_e = \gamma_e + \epsilon_e$. Thus T_i's receive ξ_s and ξ_e with some communication errors as well as observe $\xi_i = \gamma_i + \epsilon_i$. As a result, in this mode, M's choice variable x depends upon ξ_s, and T_i's choice variable y_i depends upon $\xi_s + \epsilon_{si}, \xi_e + \epsilon_{ei}$, and ξ_i, where ϵ_{si} and ϵ_{ei} denotes the commucation errors on the side of T_i.

This type of organization may be regarded as reflecting 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).

(2) Interactive R&D Organization In this type of R&D organization, M is the research manager and T_i's are interacting development teams. There is information sharing among them all regarding the systemic environment E_s. The two teams also collaborate on research and development affected by the systemic engineering environment E_e, but work individually on technical and engineering problems arising in their own segments of the engineering environment, E_i. Thus each project team in this type of organization has wide-ranging information about environments, partially shared and partially individuated. M's choice variable depends upon $\xi_s = \gamma_s + \epsilon_s$, while T_i's upon $\xi_s = \gamma_s + \epsilon_s$ (common to M and T_i's), $\xi_e = \gamma_e + \epsilon_e$ (common to T_i's), and $\xi_i = \gamma_i + \epsilon_i$ (idiosyncratic to T_i).

This type of organization may be considered as corresponding to what Stephen Klein conceptualized as the "chain-linked model" of innovation in that feedback mechanisms are operating across different levels and units (Klein and Rosenberg 1986, Aoki and Rosenberg 1989). Information assimilation is realized through the feedback of information from the lower level to the higher level, as well as through information sharing and joint development effort across design project teams on the same level.

(3) V-mediated Information Encapsulation In this type of organization, information regarding systemic environment is shared among M and T_i's as in the interactive R&D organization. However, unlike the interactive R&D organization, there is no information sharing between T_i's regarding the systemic engineering environment E_e. Thus development designs are completely encapsulated within each team and their new product design is based on individuated, differentiated knowledge. M's choice variable x depends upon $\xi_s = \gamma_s + \epsilon_s$, and T_i's upon $\xi_s = \gamma_s + \epsilon_s$ (common to M and T_i's), $\xi_{ie} = \gamma_e + \epsilon_{ei}$ (idiosyncratic to T_i's), $\xi_i = \gamma_i + \epsilon_i$ (idiosyncratic to T_i's).

Such a model may be interpreted as an internal R&D organization, with each project team having high automony in information processing and product design. However, we regard this model as capturing some essential aspects of the relationship between venture capitalists and entrepreneurial firms, as well as that among entrepreneurial firms in Silicon Valley. According to this interpretation, M is a venture capitalist and T_i's are independent entrepreneurial firms. As we already noted, there is substantial degree of information sharing among them about emergent industrial systemic environment, and venture capitalists often takes the role of intermediating such information by mediating contacts among entrepreneurs, engineers, university researchers etc.

3.2 Comparative Analysis of Information Efficiency

Since the objective function is quadratic and concave, the second-best decision rule for each agent is known to be linear in pieces of information available to and utilized by the agent (Marschak and Radner 1972, Ch.5). In the course of calculating second-best decision rules, the coefficients appearing in them turn out to be linear in the precision of information-processing activity. Here we adopt the following measure of precision of an observation according to the Bayesian theory of inference. Suppose that the prior variance of the observed environmental parameter is σ_j^2 and the variance of observation error is

$\sigma^2_{j\epsilon}$. Then the precision of observation is defined as $\Pi_j = \frac{\sigma^2_j}{\sigma^2_j + \sigma^2_{j\epsilon}}$.

For the purpose of comparison, first suppose that the above three types of organizations face the same organizational environments. Namely random variables regarding E_s,E_e,and E_i are the same across types of organization. Also suppose that the precision of prosessing information regarding those environments are equal across those types of organizations. Then tedius calculation shows the following.

Proposition 1 *Suppose that the three types of R&D organizations face the same organizational environments and constant parameters, and that, for each organizational environment, the precision of processing information is the same across those organizations. Then the V-mediated information encapsulation is informationally more efficient than hierarchical and interactive R&D organization if and only if $K > L$, namely when the choice variables of T_i's are not complementary. The interactive R&D organization is informationally more efficient than the hierarchical R&D organization.*[6]

Proof. See the Appendix.▮

Intuition behind the above proposition is as follows. If the choice variables of design projects are complementary (namely the value function is supermodular in (x, y_a, y_b)), it is more profitable to coordinate them so that they move in the same direction. Such mechanism is internalized in the hierarchical and interactive R&D organizations, since information is more assimilated in those types of organization. In contrast, in the V-mediated information encapsulation, the observations of systemic engineering environment by entrepreneurial firms are mutually hidden, so that their decision choices are less correlated.

However, the above verbal description of information processing activities in each type of organization reveals that the precision of processing information should be different across types of organization. In the interactive R&D organization, T_i's are engaged in observation and communication of E_s and E_e as well as observation of E_i's, while in the V-mediated information encapsulation, they are only engaged in observing E_e and E_i.

Therefore we expect that the precision of processing information regarding E_i's in the V-mediated information encapsulation, $\Pi_i^V (i = a, b)$, is greater than that in interactive R&D organization, $\Pi_i^I (i = a, b)$, while the precision of processing information regarding E_e and E_s in the interactive R&D organization, Π_e^I and Π_s^I, are greater than that in the V-mediated information encapsulation, Π_e^V and Π_s^V, as a result of interaction among agents.

Proposition 2 *Suppose that the three types of R&D organizations face the same constant parameters. However suppose that* $\Pi_i^V > \Pi_i^I (i = a, b)$, $\Pi_e^I > \Pi_e^V$, *and* $\Pi_s^I > \Pi_s^V$. *If the systemic environment and systemic segment of the engineering environment are relatively unimportant (*σ_{γ_s} *and* σ_{γ_e} *are small), and idiosyncratic engineering environment is relatively important (*σ_i *is large), then V-mediated information encapsulation is informationally more efficient than the interactive and hierarchical R&D organization.*

Proof. See the Appendix.■

The above two propositions are instrumental in understanding the nature of unique arrangement of R&D activities in the Silicon Valley model. The key concept is the "modularization" of a product system. This concept is often used vaguely, but it seems that the concept involves at least three aspects; (1) the standardization of interfaces between modular products; (2) the *ex post* formation of a new product system by combining new modular products; and (3) the mixture of information sharing and information encapsulation. In light of this understanding, our point is that the third aspect, which is a kind of organizational arrangement for processing information, can be understood as a consequence of the first and/or the second aspect.

First, the modularization of a product system cannot be accomplished without setting the standard for interfaces between different components. The process of standardizing interfaces usually involves detailed analyses of dependencies among designs of different components and codifying them into "design rules" (Baldwin and Clark 2000). Once codified in the standardized interfaces, the uncertainty involved in systemic and systemic engineering environments will be reduced. In addition, good architecture of a product system is such that the standardized interfaces are well formulated and remain valid for a relatively long period of time. This also adds to the reduction of uncertainty involved in the systemic environment and the systemic engineering environment, which was the hypotheses in proposition 2.

Secondly, the modularization also enables a product system to be formed evolutionarily by combining new modular products, which means that improvement of the whole system results from that of each modular product, rather than from the coordinated and simultaneous improvement of several modular products. Thus the complementarity between different project teams, as represented in the value function, will be reduced. This is the condition for the V-mediated information encapsulation to be viable in proposition 1. Thus, whatever the original cause of modularization may be, the practice of V-mediated information encapsulation fits well with the other aspects of modularization of a product system design.

The above observation also helps us understand why most success stories in Silicon Valley are concentrated on the computer industry. Once a good modular architecture is set, innovations usually take place in individual modules, and architecture and interfaces will change less frequently. The modular design of the IBM System/360 is an example. In such an environment, the complementarity between activities in different modular parts will be reduced, and the degree of uncertainty in the systemic segment of the engineering environment is low. Other examples are found in Internet/Web services.[7]

4 Incentive Aspect of the Silicon Valley Model

In Section 1 we argued that the other major role played by venture capitalists is that of governance. We now turn to exploring this aspect of the Silicon Valley model. The description of modeling background in the next subsection will show that this aspect is in fact deeply interconnected with the information-systemic aspect of the Silicon Valley model, which we analyzed in the previous section.

4.1 Description of the VC tournament game

As a background for the model below, imagine that time consists of an infinite sequence of stage games, each of which is played over four dates between venture capitalists and entrepreneurial firms. The venture capitalists live permanently, competing with one another to nurture valuable firms, while entrepreneurial firms start up at the beginning of date 2 of a stage game and exit by the end of date 4 either by going public, being acquired by other firms, or being terminated. When terminated, an entrepreneur can come back to the next stage game as a new candidate for start-up firms. In the present paper, we do not explicitly explore the repeated nature of the game, but concentrate on the analysis of the single stage game between one venture capitalist and multiple start-up firms.

At date 1, a venture capitalist, denoted by VC henceforth, screens many R&D projects proposed by cash-constrained, would-be entrepreneurs and selects some of them for start-up funding (*ex ante* monitoring). Hereafter we use a "start-up firm" and its "entrepreneur" as interchangeable terms. For simplicity, suppose there are only two types of projects. The results of these projects will be later combined to produce a product system. Let the number of selected entrepreneurs in each project be denoted by n, which is a choice variable by the VC. The start-up firms are indexed by subscript ij, where $i(=a, b)$ denotes the type of projects and $j(=1, \cdots, n)$ indexes each firm in the same project.

At date 2, each start-up firm funded by the VC is engaged in R&D activity expending effort. The choice of effort level by start-up firm ij is denoted by e_{ij} and its costs by $c(e_{ij})$ with the usual property of increasing marginal costs. The actual levels of effort expended by the start-up firms may be inferred, but are not verifiable in the courts, so that they are not contractible. The R&D effort of entrepreneur ij generates noisy one-dimensional information ξ_{ij} (research results) regarding uncertain engineering environment with the precision $\Pi_{ij}(e_{ij})$, which is increasing in e_{ij}. The higher the effort level, the higher the precision of the entrepreneur's posterior estimates regarding the environment that it faces. The fixed amount of fund provided to each entrepreneur by the VC at this date is denoted by K, which covers only the cost of processing information at this date and is not sufficient for further product development.

At date 3, communications between entrepreneurs and the VC take place. We regard this process as the process of entrepreneurs and the VC mutually improving and assimilating their estimates of the systemic environment E_s, resulting in the assimilated information ξ_s. For simplicity's sake, we suppose that the precision of their assimilated information is an increasing function $\Pi_s(\cdot)$ of the VC's mediating effort level e_{VC}. The costs associated with VC's mediating and monitoring efforts are represented by $\kappa(e_{VC})$, having the usual property of increasing marginal costs. Then each entrepreneur formulates their decisions based upon ξ_{ij} and ξ_s.[8]

At the beginning of date 4, the VC estimates which combination of a modular product design from each type of project is expected to generate higher value, if the respective firms are offered to the public, or acquired by an existing firm. According to this judgement, the VC selects one proposal from each type of project for implementation and allocates one unit of available funds to each of them. The firms that are not selected exit.

At the end of date 4, the selected projects are completed and the VC offers the ownership of these firms to the public through markets or sells it to an acquiring firm. At that time, all the environmental uncertainty is resolved and the value V is distributed among the VC and the entreprenurs. Suppose that the initial contract is such that at the time when winners are selected, a share α_i is vested with the winning entrepreneur in project $i(i = a, b)$ and the unfunded entrepreneur forfeits any share. Let us denote the distributive share of the value to the VC by $\alpha_{VC} = 1 - \sum_i \alpha_i$. The payoff to the winning firm j in project i is then $\alpha_i V - c(e_{ij})$ and that of the VC is $\alpha_{VC} V - \kappa(e_{VC}) - nK$.

4.2 Incentive Impacts of Governance by Tournament

As has been shown in the previous section, the second-best decision rules for the VC and entreprenurs turns out to be linear in the precision of processing information, $\Pi_s(e_{VC})$ and $\Pi_i(e_{ij})$. Furthermore, the resulting expected profit is also linear in $\Pi_s(e_{VC})$ and $\Pi_i(e_{ij})$.[9]

Then the expected value is an additively separable function in the effort levels by the VC and the winning entreprenurs in both types of projects. Since the winning entrepreneurs receive a fixed share of the value and the expected value is separable, the incentive effect on the entrepreneurs of the VC tournament game can be examined by considering only the tournament game within each project, to which we now turn.

Since we can now restrict our attention to a tournament within a fixed project, we henceforth suppress subscript i. There are n start-up firms selected in this project. Thus let $e_j \geq 0$ be the effort level expended by the j-th entrepreneur in the project ($j = 1, \cdots, n$) and $c(e_j)$ be its associated cost function. In order to assure that a unique interior solution exists, we assume it is increasing and convex and $c'(0) = 0, c'(\infty) = \infty$. For simplicity's sake, we further assume that the potential value created by an entrepreneur who expends effort level e_j is $y_j = g(e_j, \beta) + \epsilon_j$, where $g(e_j, \beta)$ is the expected value when an entrepreneur expends effort level e_j. We assume that $\partial g/\partial e_j > 0$, $\partial g/\partial \beta > 0$, and $\partial^2 g/\partial e_j \partial \beta > 0$. As β increases, the marginal value with respect to e_j increases. Thus β may be regarded as a parameter expressing the profitability of the project. ϵ_j is the randomness involved in the R&D activity. We assume $\epsilon_j \sim N(0, \sigma^2)$ for all j and *i.i.d.* At the beginning of date 4, the VC observes effort levels by entrepreneurs with some error, namely he observes $e_j + \epsilon_j^{VC}$ and selects the one with the highest observed value as a winning entrepreneur.[10] $e_j^{VC} \sim N(0, \sigma_{VC}^2)$ for all j and *i.i.d.* The resultant value created in the project is thus y_{j^*}, where $j^* \in \arg max_j \{e_j + e_j^{VC}\}$. Let the share of the winning entrepreneur be $\alpha \in (0, 1)$.

Summing up, the game proceeds as follows. The VC chooses the number of start-up firms in this project, n, and select entrepreneurs by screening, who then chooses their effort levels. Uncertainty about R&D activities unfolds and the VC determines the winner, observing each entrepreneur's effort levels with some noise. Finally the winner receives share α of the realized value.

Since the situation each entrepreneur faces is the same, we restrict our attention to the symmetric Nash equilibrium of this game. Let e^* be the equilibrium level of effort.

Then j-th entrepreneur's problem is described as

$$\max_{e_j} \quad \alpha g(e_j, \beta) Prob\{e_j + \epsilon_j^{VC} > \max_{i \neq j}(e^* + \epsilon_i^{VC})\} - c(e_j)$$

where $\max_{i \neq j}(e^* + \epsilon_i^{VC}) = e^* + \max_{i \neq j} \epsilon_i^{VC}$, and $\max_{i \neq j} \epsilon_i^{VC}$ is the maximum order static of a sample of size $n-1$ (Galambos 1984). Denoting the pdf and cdf of ϵ_i^{VC} by f and F respectively, the pdf of the maximum order statistics of a sample of size $n-1$ is $(n-1)f(x)F(x)^{n-2}$. So the probability that j-th entrepreneur wins is expressed as

$$Prob\{e_j + \epsilon_j^{VC} > \max_{i \neq j}(e^* + \epsilon_i^{VC})\} = \int_x (1 - F(e^* - e_j + x)) \cdot (n-1) f(x) F(x)^{n-2} dx$$

By differentiating with respect to e_j, the first-order condtition becomes

$$\begin{aligned} \alpha[\frac{\partial g(e_j, \beta)}{\partial e_j} & \int_x (1 - F(e^* - e_j + x)) \cdot (n-1) f(x) F(x)^{n-2} dx \\ & + g(e_j, \beta) \int_x f(e^* - e_j + x)(n-1) f(x) F(x)^{n-2} dx] = c'(e_j) \end{aligned}$$

Thus, in a symmetric Nash equilibrium, we have

$$\begin{aligned} \alpha[g(e^*, \beta) & \int (n-1) f(x)^2 F(x)^{n-2} dx \\ & + \frac{\partial g(e^*, \beta)}{\partial e_j} \int (n-1)(1 - F(x)) f(x) F(x)^{n-2} dx] = c'(e^*) \end{aligned} \tag{1}$$

The first term in the parentheses on the left hand side is the expected payoff times the marginal increase in the probability of winning, and the second term is the marginal payoff times the probability of winning, which turns out to be $1/n$. The next proposition should be intuitively obvious.

Proposition 3 *Consider the subgame in which entrepreneurs choose their effort levels. As the number of selected entrepreneurs increases, the equilibrium effort level decreases in a symmetric Nash equilibrium. An increase in the variance of the VC's observation error affects the incentives of entrepreneurs adversely, while an increase in profitability of the project increases the equilibrium effort level.*

Proof. Since $c'' > 0$, for the first and second parts, it suffices to show that the coefficients appearing in the parentheses in the Nash equilibrium condition are decreasing in n and σ^2_{VC}. The second term in the parentheses turns out to be

$$(n-1)\int_{-\infty}^{\infty} f(x)(1-F(x))F(x)^{n-2}dx = \int_0^1 (n-1)(1-y)y^{n-2}dy = \frac{1}{n}$$

which is obviously decreasing in n. The first term is

$$\begin{aligned}(n-1)\int_{-\infty}^{\infty} f(x)^2 F(x)^{n-2}dx &= (n-1)\int_0^1 f(x)y^{n-2}dy \\ &= [f(x)y^{n-1}]_0^1 + \int_0^1 xy^{n-1}dy \\ &= \int_0^1 F^{-1}(y)y^{n-1}dy\end{aligned}$$

and also decreasing in n. Let us denote the pdf and cdf of the standard normal distribution by ϕ and Φ respectively. Then the latter coefficient is also expressed as

$$\frac{(n-1)\int_{-\infty}^{\infty}\phi(x)^2\Phi(x)^{n-2}dx}{\sigma_{VC}}$$

which is decreasing in σ_{VC}. Finally observe that the left hand side of the Nash equilibrium condition is obviously increasing in β. ▮

Note that when there is only one entrepreneur in the project, the effort level he chooses is determined by $\alpha\frac{\partial g(e,\beta)}{\partial e} = c'(e)$. Keeping the other parameters constant, we see that the VC tournament can elicit higher efforts from entrepreneurs if and only if $g(e,\beta)\frac{\int_{-\infty}^{\infty}\phi(x)^2\Phi(x)^{n-2}dx}{\sigma_{VC}} > \frac{1}{n}\frac{\partial g(e,\beta)}{\partial e}$. This is probable when σ_{VC} is small and n is large.

Now we are in a position to turn to the VC's problem of choosing the optimal number of tournament participants. As is clear from the discussion thus far, the expected payoff of the project to the VC when the VC chooses n is (we omit additional financing cost at date 4)

$$\alpha_{VC}[g(e^*(n),\beta) + \int nxf(x)F(x)^{n-1}dx] - nK = \alpha_{VC}[g(e^*(n),\beta) + \sigma\int n\phi(x)\Phi(x)^{n-1}dx] - nK$$

where K is the costs of start-up financing. $g(e^*(n),\beta)$ is decreasing in n, because the above proposition showed e^* is decreasing in n and $g(\cdot,\beta)$ is increasing. The second term in the parentheses is the effects of running n experimentation in parallel, which is mathematically the expected value of the maximum order statistic of a sample of size n and will be proven to be increasing in n. Thus we have

Proposition 4 *Consider the VC's problem of choosing optimal number of the tournament participants. There is a trade-off between increasing the number of participants and the incentive of each participant. Furthermore, the optimal number of participants is increasing in the variance of randomness involved in the R&D activities and decreasing in the the cost of start-up financing.*

Proof. First we show that $\int_{-\infty}^{\infty} nxf(x)F(x)^{n-1}dx$ is increasing in n. By integration by part,

$$\begin{aligned}
I(n) &= \int_{-\infty}^{\infty} nxf(x)F(x)^{n-1}dx \\
&= [nx(F-1)F^{n-1}]_{-\infty}^{\infty} - \int_{-\infty}^{\infty} (F(x)-1)[nF(x)^{n-1} + n(n-1)xf(x)F(x)^{n-2}]dx \\
&= n\int_{-\infty}^{\infty} F(x)^{n-1}(1-F(x))dx + \int_{-\infty}^{\infty} n(n-1)xf(x)(1-F(x))F(x)^{n-2}dx \\
&= n\int_{-\infty}^{\infty} F(x)^{n-1}(1-F(x))dx \\
&\quad + n\int_{-\infty}^{\infty} (n-1)xf(x)F(x)^{n-2}dx - (n-1)\int_{-\infty}^{\infty} nxf(x)F(x)^{n-1}dx \\
&= n\int_{-\infty}^{\infty} F(x)^{n-1}(1-F(x))dx + nI(n-1) - (n-1)I(n)
\end{aligned}$$

By sorting the terms and dividing both sides by n, we have

$$I(n) = I(n-1) + (\int_{-\infty}^{\infty} F(x)^{n-1}dx - \int_{-\infty}^{\infty} F(x)^{n}dx) > I(n-1)$$

The objective function obviously has increasing differences in $(n, (\sigma, -\beta, -K))$, which completes the proof. ▮

The model developed above can be regarded as an extension of the VC tournament model in Aoki (2001), as well as of the model of "substitution operator" by Baldwin and Clark (2000). In the former, the number of entrepreneurs in each R&D project is fixed at two, while the latter model abstracts from the effects of increasing the number of competitors on enterpreneurs' incentives.[11] The results shown above suggest that incentive consideration can limit the effectiveness of the substitution operator substantially. The above result also shows that there will be more start-up firms engaged in the same modular products when the start-up financing cost is small, and the outcome of the R&D activity is highly uncertain and has the possibility of being very profitable. We may interpret that the dot.com bubble and crash were caused by the erroneous expectation regarding such measure of profitability. We may also point out that the number of entrants is large wherever the start-up cost is low and the business can be very profitable.

5 Conclusion

In this paper, we argued that a novel institutional arrangement for the product system innovation has emerged in Silicon Valley, and tried to capture its innovative nature by the "Silicon Valley model." We said that it is crucial to take a look at multifaceted relationships between venture capitalists on the one hand, and a cluster of entrepreneurial firms on the other. That led us to focus on the information structural relationship as well as governance relationships between them.

The analysis showed that application of the Silicon Valley model may be limited to domains in which a product system design can be partitioned into modular products by standardized interfaces, thus the technological complementarity between them is reduced; successful developmental projects are expected to yield extremely high values in markets; there are venture capitalists who are able in monitoring.

On the other hand, the identification of conditions for the informational efficiency of information encapsulation may have broader implications for corporate organizations in general. Because of the development of communications and transportation technology, even mature products (e.g. desktop computers, automobiles) are increasingly decomposed into modules, of which production and procurement become less integrated in comparison to traditional hierarchical firms (as represented by traditional American firms of a decade ago) or interactive firms (as represented by Japanese firms). This tendency renders compact modular organizations (either in the form of independent firms or subsidiaries) increasingly more efficient and viable. Various innovations in corporate governance appear to be evolving even in existing firms, somewhat emulating the Silicon Valley model, such as governing subsidiaries with flexible coupling and decoupling, less operational intervention, but with tournament-like financial discipline, which will be the subject of another paper.

Appendix

We first provide the second-best decision rules and expected payoff for each type of R&D organization. The second-best decision rules is linear in the pieces of information available as is shown by Marschak and Radner (1972, p.168). This enable us, say in the case of hierarchical R&D organization, to let $x = \lambda_s(\gamma_s + \epsilon_s)$, $y_i = \lambda_{si}(\gamma_s + \epsilon_s) + \lambda_{ei}(\gamma_e + \epsilon_e + \epsilon_{ei}) + \lambda_i(\gamma_i + \epsilon_i)(i = a, b)$ and then solve for each coefficient. The derivation method is the same across the following types of organization.

Hierarchical R&D organization In this case, the second-best decision rules turn out to be

$$\begin{aligned} x &= \frac{K + D\Pi_{se}}{AK - D^2\Pi_{se}} \Pi_s \xi_s \\ y_i &= \frac{D + A}{2(A\frac{K}{\Pi_{se}} - D^2)} \Pi_s^H(\xi_s + \epsilon_{si}) + \frac{1}{2K}\Pi_e^H(\xi_e + \epsilon_{ei}) + \frac{1}{K + L}\Pi_i^H \xi_i \quad (i = a, b) \end{aligned}$$

where

$$\begin{aligned} \Pi_s^H &= \frac{\sigma_{\gamma_s}^2}{\sigma_{\gamma_s}^2 + \sigma_{\epsilon_s}^2} \\ \Pi_{se} &= \frac{\sigma_{\gamma_s}^2 + \sigma_{\epsilon_s}^2}{\sigma_{\gamma_s}^2 + \sigma_{\epsilon_s}^2 + \sigma_{si}^2} \\ \Pi_e^H &= \frac{\sigma_{\gamma_e}^2}{\sigma_{\gamma_e}^2 + \sigma_{\epsilon_e}^2 + \sigma_{ei}^2} \\ \Pi_i^H &= \frac{\sigma_i^2}{\sigma_i^2 + \sigma_{\epsilon i}^2} \quad (i = a, b) \end{aligned}$$

By substitution, the maximized expected payoff is

$$\frac{2D + \frac{K}{\Pi_{se}} + A}{2(A\frac{K}{\Pi_{se}} - D^2)} \sigma_{\gamma_s}^2 \Pi_s^H + \frac{1}{2K}\sigma_{\gamma_e}^2 \Pi_e^H + \frac{1}{2(K + L)}(\sigma_a^2 \Pi_a^H + \sigma_b^2 \Pi_b^H)$$

Interactive R&D organization For this case, the second-best decision rules are

$$\begin{aligned} x &= \frac{D + K}{AK - D^2} \Pi_s^I \xi_s \\ y_i &= \frac{D + A}{2(AK - D^2)} \Pi_s^I \xi_s + \frac{1}{2K}\Pi_e^I \xi_e + \frac{1}{K + L}\Pi_i^I \xi_i \end{aligned}$$

where

$$\begin{aligned}\Pi_s^I &= \frac{\sigma_{\gamma_s}^2}{\sigma_{\gamma_s}^2+\sigma_{\epsilon_s}^2}\\ \Pi_e^I &= \frac{\sigma_{\gamma_e}^2}{\sigma_{\gamma_e}^2+\sigma_{\epsilon_e}^2}\\ \Pi_i^H &= \frac{\sigma_{\gamma_i}^2}{\sigma_{\gamma_i}^2+\sigma_i^2} \quad (i=a,b)\end{aligned}$$

By substitution, the maximized expected payoff is

$$\frac{2D+K+A}{2(AK-D^2)}\sigma_{\gamma_s}^2\Pi_s^I+\frac{1}{2K}\sigma_{\gamma_e}^2\Pi_e^I+\frac{1}{2(K+L)}(\sigma_a^2\Pi_a^I+\sigma_b^2\Pi_b^I)$$

V-mediated information encapsulation Here the second-best decision rules are

$$\begin{aligned}x &= \frac{D+K}{AK-D^2}\Pi_s^V\xi_s\\ y_i &= \frac{D+A}{2(AK-D^2)}\Pi_s^V\xi_s+\frac{1}{(K-L)\Pi_e^V+(K+L)}\Pi_e^V\xi_{ie}+\frac{1}{K+L}\Pi_i^V\xi_i\end{aligned}$$

where

$$\begin{aligned}\Pi_s^V &= \frac{\sigma_{\gamma_s}^2}{\sigma_{\gamma_s}^2+\sigma_{\epsilon_s}^2}\\ \Pi_e^V &= \frac{\sigma_{\gamma_e}^2}{\sigma_{\gamma_e}^2+\sigma_{ei}^2} \quad (i=a,b)\\ \Pi_i^V &= \frac{\sigma_i^2}{\sigma_i^2+\sigma_{\epsilon_i}^2} \quad (i=a,b)\end{aligned}$$

By substitution, the maximized expected payoff is

$$\frac{2D+K+A}{2(AK-D^2)}\sigma_{\gamma_s}^2\Pi_s^V+\frac{1}{(K-L)\Pi_e^V+(K+L)}\sigma_{\gamma_e}^2\Pi_e^V+\frac{1}{2(K+L)}(\sigma_a^2\Pi_a^V+\sigma_b^2\Pi_b^V)$$

Proof of Proposition 1 By assumption, σ_s, σ_{γ_e}, $\sigma_i(i=a,b)$ are all equal across types of R&D organization and $\Pi_s^H=\Pi_s^I=\Pi_s^V$, $\Pi_e^H=\Pi_e^I=\Pi_e^V$, $\Pi_i^H=\Pi_i^I=\Pi_i^V$. First observe that the only difference in the maximized expected payoff between hierarchical R&D organization and Interactive Organization lies in the coefficient of $\Pi_s^T(T=H,I)$. Since $\frac{2D+K+A}{2(AK-D^2)}$ is decreasing in K and Π_{se} is less than 1, the coefficient in the maximized expected payoff for the hierarchical R&D organization is less than that for the interactive

R&D organization. This establishes the second half of the statement of proposition 1. Now it suffices to make comparision between interactive R&D organization and V-mediated information encapsulation.

In this comparison, the only difference lies in the coefficient of $\Pi_e^T(T = I, V)$.

$$\frac{1}{(K-L)\Pi_e^V + (K+L)} > \frac{1}{2K}$$

if and only if

$$K - L > 0$$

This completes the proof.▮

Proof of Proposition 2 Letting the maximized expected payoff for V-mediated information encapsulation be greater than that for interactive R&D organization,

$$\begin{aligned} \frac{1}{2(K+L)}\left[\sigma_a^2(\Pi_a^V - \Pi_a^I) + \sigma_b^2(\Pi_b^V - \Pi_b^I)\right] > \sigma_{\gamma_e}^2 & \left[\frac{\Pi_e^I}{2K} - \frac{\Pi_e^V}{(K-L)\Pi_e^V + (K+L)}\right] \\ & + \frac{2D+K+A}{2(AK-D^2)}\sigma_{\gamma_s}^2\left[\Pi_s^I - \Pi_s^V\right] \end{aligned}$$

Since $\Pi_i^V > \Pi_i^I$ for $i = a, b$, $\Pi_s^I > \Pi_s^V$ and $\Pi_e^I > \Pi_e^V$, the above inequality holds for sufficiently large σ_i and sufficiently small σ_{γ_s} and σ_{γ_e}.▮

References

Aoki, Masahiko. *Towards A Comparative Institutional Analysis.* Cambridge, MA: MIT Press, 2001.

Aoki, Masahiko, and Rosenberg, Nathan, "The Japanese Firm as an Innovating Institution." in Takashi Shiraishi and Shigeto Tsuru, Eds., *Economic Institutions in a Dynamic Society,* pp.137-154. New York: Macmillan, 1989.

Baldwin, Carliss Y., and Clark, Kim B. *Design Rules - vol.1: The Power of Modularity.* Cambridge, MA: MIT Press, 2000.

Baldwin, Carliss Y., and Clark, Kim B, “Modularity after the Crash.” in Raghu Garud, Arun Kumaraswamy, and Richard Langlois, Eds., *Managing the Modular Age: Architectures, Networks and Organizations,* Oxford, UK: Blackwell Publishers, 2001 (forthcoming).

Cremer, Jacques, “Common Knowledge and the Co-ordination of Economic Activities.” in Masahiko Aoki, and Bo Gustafsson, and Oliver E. Williamson, Eds., *The Firm as a Nexus of Treaties*, pp.53-76. London: Sage Publications, 1990.

Fenn, George W., Liang, Nellie and Prowse, Stephen, “The Economics of the Private Equity Market,” Staff Studies No. 168. Board of Governors of the Federal Reserve System, 1995.

Galambos, Janos “Order Statistics.” in P.R. Krishnaiah and P.K. Sen, Eds., *Handbook of Statistics 4: Nonparametric Methods*, pp.359-382. Amsterdam: North-Holland, 1984.

Gompers, Paul A. and Lerner, Josh “The Use of Covenants: An Empirical Analysis of Venture Partnership Agreements.” *J. Law Econ.* **39**, 2:463-98, October 1996.

Gorman, Michael, and Sahlman, William A., “What Do Venture Capitalists Do?” *J. Bus. Venturing*, **4**, 231-48, June 1989.

Grossman, Sanford J., and Hart, Oliver, “The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration.” *J. Polit. Economy* **94**, 691-719, 1986.

Hart, Oliver, and Moore, John, “Property Rights and the Nature of the Firm.” *J. Polit. Economy* **98**, 1119-1158, 1990.

Hellmann, Thomas F., “Symantec Corporation: Acquiring Entrepreneurial Companies,” Teaching Note S-SM-27. Stanford: Stanford Business School. Nov. 1998.

Klein, Stephen, and Rosenberg, Nathan, “An Overview of Innovation.” in Ralph Landau, and Nathan Rosenberg, Eds., *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, pp.275-306. Washington, D.C.: National Academic Press, 1986.

Lerner, Josh, "The Syndication of Venture Capital Investments." *Finan. Manage.* **23**, 16-27, Autumn, 1994.

Marschak, Jacob, and Radner, Roy, *Economic Theory of Teams.* New Haven, CT: Yale University Press, 1972.

Rajan, Raghuram G., and Zingales, Luigi, "Power in a Theory of the Firm." *Quart. J. Econ.* **113**, 2:387-432, 1998.

Sahlman, William A., "The Structure and Governance of Venture Capitalist Organizations." *J. Finan. Econ.* **27**, 473-521, 1990.

Saxenian, Annalee. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128.* Cambridge, MA: Harvard University Press, 1994.

Footnotes

1. Acknowledgement

2. Rajan and Zingales (1998) is an attempt to generalize the basic model of property rights approach. They point out that the original property rights models put too much and exclusive emphasis on the ownership of physical assets as a source of power. They assert that power can come from allocation of *access* to various kinds of critical resources, such as specialized machinery, good ideas, and talented persons.

3. A similar argument is found in Baldwin and Clark (2000), which uses "DSM(design structure matrix)" and "TSM(task structure matrix)" to describe dependencies among design parameters and design tasks respectively. They define "modularization (in design)" as rationalization in the designing process of a complex product system. The information structure is said to become "hierarchical" by modularization. "Design rules" are at the top of the tree, visible by most of the task units engaged in respective component designs; interfaces are in the middle of the tree and visible by design task units who need to know them. At the base of the tree, there is information that is hidden within each task unit.

4. This payoff function may be thought of as a second-order Taylor series approximation of a general payoff function around the optimal values of x and y_i's with respect to the prior distribution of the stochastic parameters. We also normalize the payoff so that the expected payoff is zero when there is no *ex post* information other than the priors.

5. Namely its Hessian matrix is negative definite.

6. This proposition can be seen as an extension of a theorem due to Cremer (1990). In the hierarchical R&D organization, the communication is one-directional and thus involves communication errors, while in the interactive R&D organization information is completely shared. This is the reason why the interactive R&D organization

is informationally more efficient than the hierarchical R&D organization. Considering the cost saved by one-directional communication would change the result. However we will not be concerned about the comparison between the interactive R&D organization and the hierarchical R&D organization hereafter.

7. Baldwin and Clark (2000) regard "modularization-in-design" as rationalization in the process of designing a complex product system. When they demonstrate how to modularize a product design by using Design Structure Matrix, modularization is primarily to contrive an ideal hierarchical information system within the whole design process. Once this is done, or at the same time this is done, other aspects of modularization, such as reduced complementarity between different design tasks, information encapsulation etc., are supposed to come together immediately. In this sense, our approach is more analytical. It may also be said that we are deriving a second-best organizational arrangement with technological parameters given. Such a difference in the approach may make somewhat subtle difference between our argument and theirs. According to our analysis, the practice of V-mediated information encapsulation is not realizable if there is indispensable complementarity between project teams or systemic environment is necessarily very important. Some sort of product system may not be modularized because of such difficulties.

8. We abstract from the systemic segment of the engineering environment E_e, because it can be thought of as relatively unimportant (its variance is low) where the Silicon Valley model is applied. See proposition 2 and the subsequent argument.

9. More specifically, abstracting from E_e, the second-best decision rule of the VC is $x^* = \frac{D+K}{AK-D^2}\Pi_s\xi_s$, and that of entrepreneur ij is $y^*_{ij} = \frac{D+A}{2(AK-D^2)}\Pi_s\xi_s + \frac{1}{K+L}\Pi_{ij}\xi_{ij}$ in the V-mediated information encapsulation. The resultant expected profit when the VC has selected entrepreneur j from project a and k from b is $\frac{2D+K+A}{2(AK-D^2)}\sigma^2_{\gamma_s}\Pi_s + \frac{1}{2(K+L)}(\sigma^2_a\Pi_{aj} + \sigma^2_b\Pi_{bk})$.

10. It may appear to be more natural to assume that the VC observes the potential value

rather than the effort levels by entrepreneurs. However the qualitative properties do not change even if we adopt such a modeling strategy. Furthermore, the distinction between the effects caused by σ and σ_{VC} will become difficult to make in such a model.

11. In the model of Baldwin and Clark (2000), the result of R&D activity in the current period is adopted if it turns out to be superior to the old one. Namely they regard the result of R&D activities in modular designs as "real options." They suggest that the more the number of parallel experiments, the more the value of real options, which they name the "value of substitution." Although our model does not explicitly model the value of VC tournament as real options, the same increasing property can be obtained. Namely increasing the number of entrepreneurs has the effect of mounting more experiments parallelly.