IEMS Vol. 6, No. 1, pp. 55-63, June 2007.

Proper Incentives to Promote Information Exchange

Atsuomi Obayashi†
Graduate School of Business Administration
Keio University, 2-1-1 Hiyoshi-honcho, Kohoku-ku, Yokohama 223-8523, Japan
+81-45-562-1185, E-mail: obayashi@kbs.keio.ac.jp

Received Date, November 2005; Accepted Date, December 2006

Abstract. Exchange of information is essential to the process of innovation such as product development. However, in many cases innovation fails because of a lack of knowledge sharing among parties concerned, even if parties individually have pieces of useful knowledge and skills. Besides physical factors like communication costs, the possibility of opportunistic behavior by parties like stealing ideas can discourage information exchange. This paper introduces a model to analyze incentives of information exchange. The model is a game by two players who alternately opt to offer information to the partner. It is suggested that information exchange can stop before reaching the efficient level. In order to attain the efficient information exchange, expectation of mutual benefit and absence of opportunistic motives in both players are needed. Methods for promoting information exchange include modifying payoff structure to meet the condition of information exchange. The fluidity of partnership may increase a variety of information exchange partners, but discourage building trust between partners which promotes information exchange.

Keywords: Information Exchange, Incentive, Innovation, Search, Opportunistic Behavior.

1. INTRODUCTION

Promoting innovation such as new product development is an area of concern for many practitioners and researchers alike. Roberts (1989), Saxenian (1996) and Lee (2000) present that a new product is born not from a single idea but from constant accumulation of knowledge coupled with collaboration with others. Cases of stagnant product development often reveal that, innovation fails because of a lack of knowledge sharing among parties concerned, even if parties individually have pieces of useful knowledge and skills. On the contrary, many cases of successful product development are found to be a result of active communication between parties concerned.

Innovation is usually not an individual effort but a result of trail and error process involving multiple people exchanging information. In addition, there must be something common between the people besides diversity in their knowledge so that they may exchange information. Although new value is created when heterogeneous types of knowledge are combined, such combination requires common knowledge background which allows understanding and providing an appropriate feedback to the information provided. Therefore, one tends to exchange information with those engaging in the same industry or those with the same expertise as his own. This means that one may end up helping his competitor by sharing his information. One from the same industry or the same field of work may turn into your competitor. By offering information you may suffer a loss if the recipient of information outwits you by making use of it. Such an opportunistic use of information is likely to happen between organizations as well as between individuals in an organization.

People may gain or lose from information exchange. Therefore, information sharing does not occur automatically, even if parties individually have pieces of useful knowledge. This paper proposes a method of promoting information exchange from a viewpoint of incentives. An analysis of incentives is conducted based on a model in which players exchange information under uncertainty. The model shows that, when the other player is anticipated to stop offering information in future, the player also stops sharing his information in advance in order to protect his own interest. This behavioral chain reaction inhibits information exchange and information exchange can stop before reaching the efficient level. In order to attain the efficient information exchange, expectation of mutual benefit and absence of opportunistic motives in both players are needed.

Information exchange can be promoted through satisfying functional conditions, such as improving information quality and reducing communication cost, as well as through conditions related to behaviors, such as prevention of opportunistic use of information. Condi-

† : Corresponding Author

tions for promoting information exchange should be satisfied by both parties concerned. One must let the other party, with whom one wants to promote communication, know that one has valuable information to offer and that one will not behave to inflict any loss to the other party. To win confidence in the other party, you must create a structure of incentives conductive to information exchange.

2. PREVIOUS STUDIES

Many studies on innovation assume the linear model. Linear model is a model in which innovative outputs are progressively forwarded from one stage to the next, from basic research, applied research, product development, manufacturing, to marketing. It is questionable, however, if innovation, which essentially involves generating knowledge, is carried out in a process similar to that of manufacturing products. There have been criticisms about the linear model on the ground that most part of actual product development involves more than one-way flow from upstream to downstream (Kline and Rosenbertg, 1986; Rosenboom and Spencer, 1996; Niwa and Yamada, 1999). According to the linear model, information from the market is not reflected on products, nor is information from manufacturing floor reflected on design. In fact, these are common issues raised as factors obstructing product development.

Kline (1985, 1990) proposed a chain-linked model as an antithesis to the linear model. It assumes a reverse feedback flow as well as the upstream to downstream flow. Parties are linked by two-way exchange of information. The chain-linked model is reputed for representing product development especially in assembly manufacturing industry. This model, however, does not express incentives allowing information exchange.

While analysis of incentives is an area covered by economics, few studies have been conducted in economics about the process of how innovation occurs. A likely reason why this is the case is that the mainstream model employed in economics is optimization among known alternatives, which is not good at expressing a process to create something unknown. Although neo-classical economic growth theory accepts innovation to be a source of sustained economic growth, innovation itself is expressed as relatively simple, stochastic process. For example, the model proposed by Grossman and Helpman (1991) defines the probability of innovation occurrence as an increasing function of input into research and development by a single agent, and not as a function of information exchange among agents nor a function of the inputs by multiple agents.

Game theory is suitable for analyzing incentives for multiple agents. The class of negotiation games suggested by Rubenstein (1982) and others model the process of information exchange. The negotiation game, however, assumes exchange of offers and counteroffers to split a pie of a given size. Information exchange for innovation, on the contrary, involves enlarging the pie rather than splitting a pie of a limited size, or creating a new pie, and presents a very different situation. Besides, innovation is characterized often by information exchange over a very extended period, which makes it difficult to predict its process and payoffs correctly in advance. Innovation has an exploratory nature; information starts getting exchanged when processes and results are still uncertain, which gradually become clearer at a later stage. Therefore, it is not realistic to describe the entire process of innovation as a group of explicit alternatives and payoffs, as done in a game typically used in economics. Instead, it is necessary to devise a game suitable to describe the exploratory nature of innovation.

3. MODEL

A model proposed in this paper should have the following features. First, the model analyzes incentives for multiple agents to exchange information. As it is mentioned in the previous section, a game model is suitable to analyze incentive problems of multiple agents. Second, the model expresses exploratory nature of innovation, that is, information exchange is not a result of optimization with perfect information. The model is supposed to include uncertainty which is resolved as information exchange advances.

3.1 Definition

This paper proposes a generic model of information exchange. The model is an extensive-form game by two players, i.e. A and B, as shown in Figure 1. The game starts with A's move, and decisions are made alternately by A and B whether or not they provide information. The game continues so far as information keeps being offered, and if either player stops offering information, the game ends at that particular node. The assumption that players offer information alternately will not be too strong because one player's successive information provisions are considered to be a provision of multiple information units, which can be represented by one node in the game. Although Figure 1 shows an example of A's move being the last, either player's move could be the last depending on the node number. With the number of nodes being indicated as n, A's payoff when the game ends at the i'th node is shown as A_i, and B's payoff is B_i. At the last node, the payoffs of A and B if information is not provided is expressed as (A_n, B_n), and (U_A, U_B) if information is provided. Player's payoff is an expected value of innovation achievable by the player himself with his information. Where information is exchanged until the last node, however, collaboration by A and B may ensue, and therefore, payoffs (U_A, U_B) indicate expected benefits including the possibility of collaboration.

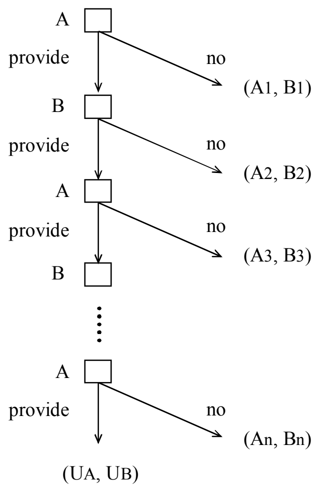


Figure 1. Model of Information Exchange

Every time where information is offered at each node, the player who receives the information increases his payoff by increased information. On the other hand, the player who provided information finds his payoff decreased by reduced monopoly of information as well as by bearing the cost of producing the information. That is to say, the player's payoff repeats increasing and decreasing as the node advances. The loss involving decreased monopoly of information includes the loss of the information being utilized by the other player and the loss of the information is leaked to the third party. Relationship of payoffs in two consecutive nodes is represented in the following formulas.

$$A_{i+1} = A_i + g_{Ai} - l_{Ai} - c_{Ai} \qquad (1)$$
$$B_{i+1} = B_i + g_{Bi} - l_{Bi} - c_{Bi} \qquad (2)$$

g_{Ai} is the benefit A obtains because of the information he receives at the i'th node. l_{Ai} is the loss incurred on A by his offering information at the i'th node. c_{Ai} is the physical cost incurred on A for producing and providing information at the i'th node. g_{Bi}, l_{Bi} and c_{Bi} correspond to g_{Ai}, l_{Ai} and c_{Ai}, respectively, with the player being replaced with B. If i is an odd number, A can provide information there, and $g_{Ai} = 0$, $l_{Ai} > 0$, $c_{Ai} > 0$ hold. On the other hand, B receives information and $g_{Bi} > 0$, $l_{Bi} = 0$, $c_{Bi} = 0$ hold. If i is an even number, it is B's move, and $g_{Ai} > 0$, $l_{Ai} = 0$, $c_{Ai} = 0$ and $g_{Bi} = 0$, $l_{Bi} > 0$, $c_{Bi} > 0$ hold. The loss of information giver, i.e. l_{Ai} (or l_{Bi}) and the benefit received by the recipient at the node, i.e. g_{Bi} (or g_{Ai}) are not equivalent. Benefit may be greater or smaller than the loss. Likewise, you cannot tell which is greater for one player, the benefit he obtains at a node, i.e. g_{Ai} (or g_{Bi}) or the loss he receives from providing information at another node, i.e. l_{Ai+1} (or l_{Bi+1}).

An exploratory nature of innovation is expressed in the following way. In reality, information may be exchanged extremely many times, and therefore, it is impossible to predict correctly the value of information exchanged in each time. To model the exploratory nature of innovation, the scope of representation in the game is restricted to the nodes at which value of information is predictable. In other words, the last node of the game is where players find limit in predicting the value of information exchanged each time. Conceptually, players can continue to exchange information after reaching the last node depicted in the game. To which level they may do so, however, can not be described with nodes at the starting point of the game. Therefore, the game expresses this by incorporating expected benefit through further information exchange into the payoff at the last node, U_A and U_B. Expressing the expected benefit as α and β, U_A and U_B are expressed as (3) and (4) below ($\alpha \geq 0$, $\beta \geq 0$). Even though it is the last node depicted in the game, U_A (or U_B) can be greater or smaller than A_n (or B_n) depending on values of α and β.

$$U_A = A_n + g_{An} - l_{An} - c_{An} + \alpha \qquad (3)$$
$$U_B = B_n + g_{Bn} - l_{Bn} - c_{Bn} + \beta \qquad (4)$$

Each player behaves so that his payoff becomes maximum. Where the same payoff results either from providing or not providing information, he provides information. Excluded from this model are information provision which improves the payoff of both players, as in the case where communication protocol is arranged, because it does not induce an incentive problem. Moreover, provision of information which reduces the payoff of the recipient, such as information to deceive him, shall also be excluded (In this case, however, the recipient's payoff does not decrease if he notices that the information provided is false.).

3.2 Equilibrium

The model has the following equilibrium. Proof of equilibrium is listed in the appendix at the end of this paper.

Equilibrium. *Where $U_A \geq A_i$ holds for every odd number i that satisfies $1 \leq i \leq n$, and where $U_B \geq B_i$ holds for every even number i that satisfies $1 \leq i \leq n$, information is provided at every node from the first to the n'th node. In cases other than these, the game finishes immediately without A providing information at the first node.* (5)

Equilibrium can be interpreted as described below. A precondition for information exchange is that, for players who make decisions at each node, exchanging information until the last node must result in larger payoff than to terminate it at earlier node. This condition needs to be satisfied at every node. If there is any node where it is more beneficial for either player to finish the game there, that player would terminate the game at that node without providing information. The other player anticipating this to happen, stops offering information at a node immediately before that node to avoid his own loss. The other party, in turn, tries to avoid loss by preempting the move. This preemptive thinking may go back to the first node to preclude any act of exchanging information.

Cases where $U_A < A_i$ or $U_B < B_i$ holds, which induce suspension of the game, specifically, are those where expected benefit U_A or U_B is small, or where benefits associated with opportunistic use of information are large. (If a player is able to outwit the other and monopolize innovative output at a stage where he has yet to share much information, A_i or B_i becomes large.) Expressing this from a broader perspective, payoffs of both players must show an increasing trend with relatively small fluctuations in order for information exchange to take place. Without such payoff structure, information exchange does not begin any way.

In general, equilibrium of this game is not efficient. An efficient outcome is where information is exchanged until the node where $A_i + B_i$ becomes maximum. At an equilibrium, however, efficient information exchange may not happen. What follows in (6) is a case in point where $n = 3$.

$$\begin{aligned} &A_1 = 0, && B_1 = 0, \\ &A_2 = -4, && B_2 = 8, \\ &A_3 = 4, && B_3 = 4, \\ &U_A = 7, && U_B = 7 \end{aligned} \tag{6}$$

The sum of payoffs become maximum where information exchanged until the end and the payoffs, $U_A = 7$, $U_B = 7$, are realized. (Optimum information exchange is not necessarily one which is carried on until the last node.) Where $i = 2$, however, $U_B < B_2$ holds, and the game ends at the first node with $A_1 = 0$, $B_1 = 0$. Since $B_2 = 8$ is greater than U_B, it is more beneficial for B to end the game at the second node, and A, knowing the fact, does not provide information at the first node. Equilibrium payoff, $A_1 = 0$, $B_1 = 0$, is a result of low payoff for both players in comparison with the efficient outcome. The payoff structure is such that B_2 having become so large that mutually incremental payoff structure has given way. A spike in the payoff structure inhibits effective information exchange.

4. SUGGESTIONS FOR PROMOTING INFORMATION EXCHANGE

As exemplified in the last paragraph of the previous section, improper incentive may obstruct forming the "mutually incremental" payoff structure, discouraging information exchange. Solution to this problem for the purpose of promoting information exchange will be proposed based on an analysis of the model. As a preparation, payoffs of the model are broken down into some components in Sections 4.1 and 4.2. Then, in Section 4.3 and onwards, methods for promoting information exchange are proposed.

4.1 Breakdown of Payoffs into Components

Repeating the algorithm of formula (1), payoff of the player A at each node is expressed as follows.

$$A_2 = A_1 + g_{A1} - l_{A1} - c_{A1} \text{ (Substitute } i = 1 \text{ into (1))} \tag{7}$$

$$\begin{aligned} A_3 &= A_2 + g_{A2} - l_{A2} - c_{A2} \text{ (Substitute } i = 2 \text{ into (1))} \\ &= A_1 + g_{A1} + g_{A2} - l_{A1} - l_{A2} - c_{A1} - c_{A2} \quad \text{((7) into above)} \end{aligned} \tag{8}$$

$$\begin{aligned} A_4 &= A_3 + g_{A3} - l_{A3} - c_{A3} \text{ (Substitute } i = 3 \text{ into (1))} \\ &= A_1 + g_{A1} + g_{A2} + g_{A3} - l_{A1} - l_{A2} - l_{A3} - c_{A1} \\ &\quad - c_{A2} - c_{A3} \quad \text{((8) into above)} \end{aligned}$$

The same is continued further. Generally A_i is expressed as follows.

$$A_j = A_1 + G_{Aj-1} - L_{Aj-1} - C_{Aj-1} \tag{9}$$

G_{Aj-1} is the sum of g_{Ai} for every i that satisfies $1 \le i \le j-1$. L_{Aj-1} is the sum of l_{Ai} for every i that satisfies $1 \le i \le j-1$. C_{Aj-1} is the sum of c_{Ai} for every i that satisfies $1 \le i \le j-1$. G_{A0}, L_{A0}, and C_{A0} are all zero. As in the case of A_j in the formula (9), B_j is expressed as follows.

$$B_j = B_1 + G_{Bj-1} - L_{Bj-1} - C_{Bj-1} \tag{10}$$

G_{Bj-1}, L_{Bj-1} and C_{Bj-1} are the sum of g_{Bi}, l_{Bi} and c_{Bi}, respectively, for every i that satisfies $1 \le i \le j-1$. G_{B0}, L_{B0} and C_{B0} are all zero.

Substituting formula (9) into A_n of formula (3) and formula (10) into B_n of formula (4), U_A and U_B are expressed respectively as follows.

$$\begin{aligned} U_A &= A_n + g_{An} - l_{An} - c_{An} + \alpha \\ &= A_1 + G_{An} - L_{An} - C_{An} + \alpha \end{aligned} \tag{11}$$

$$\begin{aligned} U_B &= B_n + g_{Bn} - l_{Bn} - c_{Bn} + \beta \\ &= B_1 + G_{Bn} - L_{Bn} - C_{Bn} + \beta \end{aligned} \tag{12}$$

4.2 Breakdown of Conditions for Information Provision

Payoffs which are broken down into components as in formulas from (9) to (12) are substituted for conditions for information provision in the description of equilibrium (5). For information to be provided, condition, $U_A \ge A_i$, must be satisfied for every i that is odd number satisfying $1 \le i \le n$. Replacing formula (11) and (9) for U_A and A_i, respectively, $U_A \ge A_i$ will be equivalent to the formula below.

$$A_1 + G_{An} - L_{An} - C_{An} + \alpha \ge A_1 + G_{Ai-1} - L_{Ai-1} - C_{Ai-1} \tag{13}$$

Transposing the formula (13) results as follows:

$$(G_{An} - G_{Ai-1}) - (L_{An} - L_{Ai-1}) - (C_{An} - C_{Ai-1}) + \alpha \geq 0 \quad (14)$$

In addition to the formula (14), for information to be provided, the condition, $U_B \geq B_i$, must also be satisfied for every i that is an even number satisfying $1 \leq i \leq n$. Substituting formula (12) and (10) for U_B and B_i, respectively, transposing and arranging, $U_B \geq B_i$ will be equivalent to the formula below.

$$(G_{Bn} - G_{Bi-1}) - (L_{Bn} - L_{Bi-1}) - (C_{Bn} - C_{Bi-1}) + \beta \geq 0 \quad (15)$$

Combining the conditions satisfying formulas (14) and (15) for i which is odd number and even number, respectively, conditions required for information provision, which is stated in the equilibrium condition of (5), can be restated as follows.

$$\text{“}G_i - L_i - C_i + x \geq 0 \text{ holds for every i that satisfies } 1 \leq i \leq n.\text{”} \quad (16)$$

G_i in (16) represents G_{An}-G_{Ai-1} where i is an odd number, and G_{Bn}-G_{Bi-1} where i is an even number. L_i represents L_{An}-L_{Ai-1} where i is an odd number and L_{Bn}-L_{Bi-1} where i is an even number. C_i represents C_{An}-C_{Ai-1} where i is an odd number and C_{Bn}-C_{Bi-1} where i is an even number. x represents α where i is an odd number and β where i is an even number.

Conditions of (16) tell us that the greater the value G_i, which increases through information exchange, the smaller the loss L_i and the greater the expected benefit x, the more likely is information provision to happen. Methods of promoting information exchange are proposed along this line in Section 4.3 and subsequent sections.

4.3 Promoting Information Exchange From Functional Aspect

Enhancing the value of information to be exchanged and reducing the cost of information production and communication lead to increased G_i, decreased C_i and increased x. Every one of them is conducive to meeting conditions (16) for information provision. If, for instance, information production based on a real trial and error process can be replaced by computer simulation, cost C_i can be saved both in terms of time and money. If the other party with whom information is exchanged is highly competent, you may be able to obtain high-quality information, thus G_i and x are great, and information communication may be smooth, making C_i small. To facilitate information exchange, however, you must also be selected as his partner. This mutuality is expressed in the conditions (16) for information provision that the conditions must hold for every i, that is, both players. The more highly competent you may be, the greater the possibility would be for exchanging information.

4.4 Promoting Information Exchange By Preventing Opportunistic Use of Information

Intellectual property rights and confidentiality agreements generally help minimize L_i through restricting opportunistic use of information. (Depending on how use is restricted G_i can also be decreased.) If those who exchange information with each other compete in the same market, the motive for stealing ideas becomes great for leveraging leader's benefit, thus making L_i great. In technology licensing contracts between companies, segregating their product ranges and/or markets may reduce L_i through preventing competition.

Exchanging small amounts of information frequently instead of transferring it at one time may also be effective in preventing opportunistic behaviors. This method influences on gain and loss for every node rather than on total loss L_i. Transferring small amounts of information every time corresponds to small g_{Ai}, g_{Bi}, l_{Ai}, and l_{Bi} in the model. In the example shown in (6), benefits of receiving information g_{B1} and g_{A2} are 8, while loss of giving information l_{A1} and l_{B2} are 4 (c_{A1} and c_{B2} are zero.) In this example, there is a motive for suspending the game, and information does not get provided from the beginning. Let us assume the case of exchanging the same amount of information in (6) in two rounds instead of one round. Then, both the benefit of receiving information and loss get halved to 4 and 2, respectively, and information exchange in two rounds where n=5 will have payoff shown in (17) below.

$$\begin{array}{ll} A_1 = 0, & B_1 = 0, \\ A_2 = -2, & B_2 = 4, \\ A_3 = 2, & B_3 = 2, \\ A_4 = 0, & B_4 = 6, \\ A_5 = 4, & B_5 = 4, \\ U_A = 7, & U_B = 7 \end{array} \quad (17)$$

In (17), conditions of $U_A < A_i$ or $U_B < B_i$, which induce suspension of the game do not exist, allowing information exchange to take place. The payoff structure of both players is improved to one of mutually incremental one. The higher the frequency of information exchange, the smaller the fluctuation of payoff at each node, limiting chances of motives for suspension being born. In reality, increased frequency often causes a delay in information exchange. In other words, absence of motives for opportunistic behavior, or, presence of mutual trust, increases speed of information exchange. Although increased frequency of information exchange is easy to implement, increased times of communication may result in increasing cost C_i. It must also be remembered that, depending on the nature of information, it may not be broken into small portions.

Even if increased frequency of information exchange is not feasible, x becomes larger if expected benefits from collaboration are large, suppressing opportunistic behaviors. Let us assume that, if a long-term relationship exists between players, many expected benefits from future information exchange and joint innovation besides ongoing information exchange on the current topic are included in x. Since the player who takes an opportunistic behavior loses opportunity for future joint innovation, the greater the possibility of future joint innovation may be, the smaller the benefits of opportunistic behavior relative to x will become, thus functioning to control opportunistic behaviors.

From the viewpoint of preventing opportunistic behaviors, long-term relationships may facilitate information exchange. Sharing information always with same partners, however, is not efficient in merging heterogeneous bodies of knowledge. Since long-term relationship could be both promoting and impeding factor for innovation, obtaining appropriate mobility of partners is advised according to the situation.

4.5 Mutuality of Conditions of Information Exchange

Conditions for materializing information exchange must be satisfied by both players. Therefore, for the other party with whom one wants to promote information exchange, one must let him know that one can offer information valuable to him (which increases his G_i and x) along with having him expect that one will behave not to cause any disbenefit (which decreases his L_i). In order to win trust of the other party in your behaviors, it is effective to let him know that one expects benefits from long-term information exchange (i.e. one's x is large), as well as to exchange information in portions in increased frequency.

If the other party has a concern about your opportunistic behaviors, even a confidentiality agreement which restricts your behaviors alone may enable information exchange which otherwise is unlikely by reducing L_i of the other party, which results in increasing your own benefits. Likewise, where the other party cannot expect positive benefits from exchanging information, entering into an agreement for transferring part of your benefits to the other party may help creating mutually beneficial structure, enabling information exchange and producing your own benefits.

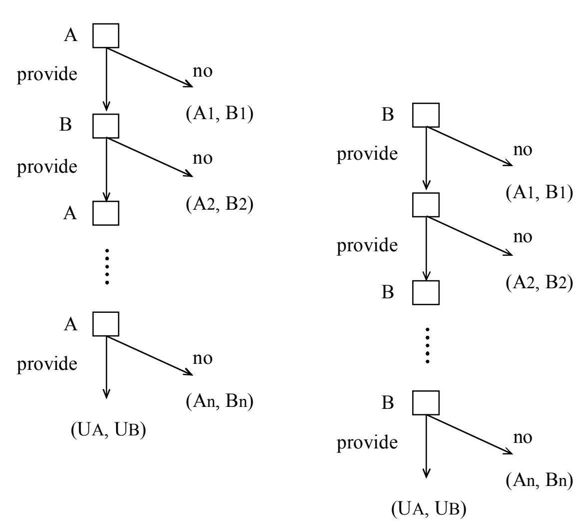
5. EXTENSIONS

5.1 Exploratory Nature of Innovation and Multiple Games Representation

Equilibrium of the model leads to two extreme results: one where information is offered at every node; and the other where information provision does not occur at all. Actual information exchange is more likely to result in somewhere between rather than such extremes. For example, information may be exchanged up to a certain point, where it halts before reaching what is considered sufficient. This halfway phenomenon may be understood by considering an exploratory nature as described below.

Innovation is an exploratory activity. As more information gets exchanged, players' information increases, enabling them to predict their payoffs further into future. The model proposed in this paper describes a snap shot of dynamic innovation process recognizing limits of players' predicting ability. For expressing gradual elucidation of information, different games need to be used for different prediction limits. Interpretation of equilibrium of model becomes more realistic if multiple games are developed in accordance with progress of information exchange.

The following situation is assumed for explaining this point. Every time when either player provides information (which corresponds to the game advancing by one node), players' limit of prediction extends also by one node. In other words, as information exchange continues, players are assumed to be able to predict always payoffs up to n node ahead. Supposing A provides information at the first node of the model shown in Figure 1 based on this assumption, a subsequent situation starting with B's move is modeled as Figure 2(b) below. For comparison, Figure 1 model is placed next as Figure 2(a). Note that 2(a) and 2(b) are different games, though they use same notations. The second node in Figure 2(a) corresponds to the first node in Figure 2(b). Therefore, (A_2, B_2) in (a) corresponds to (A_1, B_1) in (b). In (b), the n'th node is added in accordance with extended prediction limits. U_A, U_B, A_n, and B_n in (b) are newly clarified information and differ from parameters with the same names in (a). In innovation it is normal that expected value changes as information increases, and values of U_A, U_B, A_n, and B_n in (b) are determined independent from U_A and U_B in (a).



(a) Original game (b) Subsequent game

Figure 2. Models of Information Exchange

Comparison of (a) and (b) in Figure 2 indicates that they are identical except for the fact whether player A or B is the first mover. Hence equilibrium of (b) is as follows by replacing A and B in (5).

Equilibrium of the game in Figure 2(b). *Where $U_B \geq B_i$ for every i that is an odd number satisfying $1 \leq i \leq n$, and where $U_A \geq A_i$ for every i that is an even number satisfying $1 \leq i \leq n$, information is exchanged at every node from the first to the n'th node. In cases other than these, the game finishes immediately without B offering information at the first node.* (18)

Naturally, interpretation of (18) corresponds to conditions similar to the equilibrium of (5).

Let us move the situation by one more step and model the situation which again starts with A's move, assuming that B has offered information at the first node in Figure 2(b). Then, the third node in Figure 2(a) becomes the first node, where the game lasts for n nodes. This shows exactly the same model as Figure 2(a), to which equilibrium described in (5) applies as it is. Since the model returns to the same configuration after two nodes, no matter how many times information is exchanged, characteristics of the model remain the same, with just equilibrium (5) and (18) being repeated.

The assumption of this section, that prediction limit extends each time player makes move, affects the interpretation of equilibrium in a subtle way. Since game changes every time information is provided, equilibrium of a "snap-shot" game should be valid only for the first move. The correct move at the second node could be changed if game is changed as prediction limit extends. Therefore, the words "information is provided at every node" in the equilibrium should be interpreted as "information is provided at every node (so far as the game remains unchanged)." If the game changes every time when it advances by one node, what equilibrium expresses is always behaviors at the first node at a specific point in time.

Considering changes of the game, equilibrium of the model can be interpreted as follows. Unless there is any inducement for either player to interrupt information exchange within predictable limits, information exchange gets started for the time being. Information exchange is continued so far as no inducement for suspension is anticipated. Then, at a point where an inducement for future suspension emerges to either player, information exchange promptly stops there. Suspension of information exchange once started can be explained through considering a series of games as described above.

5.2 n-Player Game

Although the model proposed in this paper is a two-player game, a game with three or more players holding similar rules of the game has equilibrium of similar feature as that of the two-player game. For example, let us assume a game with three players; A, B and C. The game has players' moves and payoffs as shown in Figure 3, which is a natural extension of the two-player game in Figure 1. With the number of nodes being indicated as n, A's payoff when the game ends at the i'th node is shown as Ai, B's payoff is Bi, and C's payoff is Ci. At the last node, the payoffs of A, B and C if information is not provided is expressed as (An, Bn, Cn), and (U_A, U_B, U_C) if information is provided.

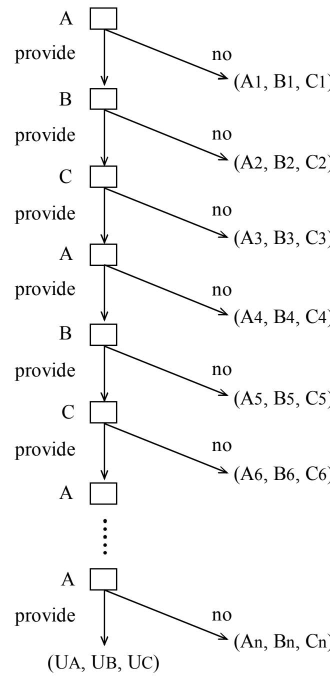


Figure 3. Three-Player Model

This three-player game has the following equilibrium.

Equilibrium of the three-player game. *Where $U_A \geq A_i$ holds for every number i that is 1, 4, 7,…, and where $U_B \geq B_i$ holds for every number i that is 2, 5, 8,…, and where $U_C \geq C_i$ holds for every number i that is 3, 6, 9,…, information is provided at every node from the first to the n'th node. In cases other than these, the game finishes immediately without A providing information at the first node.* (19)

Interpretation of (19) is similar to that of the two-player equilibrium in (5). A precondition for information exchange is that, for players who make decisions at each node, exchanging information until the last node must result in larger payoff than to terminate it at earlier node. This condition needs to be satisfied at every node.

The feature of equilibrium is alike even if the game is extended to have more than three players. Most of the results derived from the two-player game can be applied generally to n-player situation. Therefore, the method for promoting information exchange suggested in Section 4 is applicable to n-player situation as well.

6. CONCLUSION

Incentive analysis using the game proposed in this paper clarifies condition of information exchange. Even if sharing information can improve payoffs of agents, information exchange may not occur unless dynamic payoff structure is appropriate. In order for information exchange to take place, payoffs of players must show a general upward trend and fluctuations in player's payoff must be small so that benefit of opportunistic use of information is contained.

There are broadly two ways of promoting information exchange for innovation. One is to enhance the value of information to be exchanged, while reducing the cost of information exchange. This involves making information exchange more promising in terms of expected benefits. The other method is to prevent an opportunistic use of information. For this purpose, it is necessary to establish a structure whereby payoff of each party increases gradually as they continue to exchange information. Payoff structure can be modified to "mutually incremental" one by means of agreements and/or by increasing frequency of information exchange. In practice, increasing frequency and stepwise communication may cause a delay in information exchange. However, if increasing frequency is the only way of enabling information exchange, stepwise communication is not a waste of time but an efficient manner of exchanging information.

The game introduced in this paper is a simplification of actual information exchange process. Among the costs of simplification is assumption of common knowledge between players, which is not always realized in practice. People may have different expectation about gain and loss by exchanging information. On the other hand, alternating offers of the model will not be overly strong assumption because it conceptually represents both alternating and successive offers, as it is explained in Section 3.1.

The model of this paper demonstrates functional and behavioral problems involved in information exchange for innovation and shows different solutions for different problems. Basic feature of the solutions is applicable to situation with n players in general.

APPENDIX: PROOF OF EQUILIBRIUM IN (5)

Equilibrium of the model (5) is derived as in the following based on the mathematical induction.

(i) Equilibrium of the model where n=1 is as follows:

"Where $U_A \geq A_1$, A provides information at the first node. In other cases, the game finishes without A providing information at the first node."

This is equal to the result of substituting $n = 1$ into (5) in the body of the text.

(ii) Equilibrium of the model where $n = k$ is assumed to be as in the following quotation marks:

"Where $U_A \geq A_i$ holds for every i that is an odd number satisfying $1 \leq i \leq k$, and at the same time, where $U_B \geq B_i$ holds for every i that is an even number satisfying $1 \leq i \leq k$, information is provided at every node from the first to the k'th. In other cases, A does not offer information and the game finished immediately at the first node."

This is equal to the result of substituting $n = k$ into (5) in the body of the text.

(iii) Then, equilibrium of the model where moves of A and B are replaced at $n = k$ is as follows:

"Where $U_B \geq B_i$ holds for every i that is an odd number satisfying $1 \leq i \leq k$, and at the same time, where $U_A \geq A_i$ holds for every i that is an even number satisfying $1 \leq i \leq k$, information is provided at every node from the first to the k'th. In cases other than the above, the game finishes immediately at the first node without B offering information."

(iv) Next, equilibrium of the model where $n = k + 1$ is derived.

The subgame after the second node of the model $n = k + 1$ has the same configuration as the model $n = k$, except that the moves of players A and B are interchanged. Therefore, equilibrium of the subgame after the second node is obtained by advancing the node number by one each in the equilibrium of (iii) with players being interchanged (Since node number is advanced by one, odd and even numbers are reversed.).

"Where $U_A \geq A_i$ holds for every odd number i that satisfies $2 \leq i \leq k+1$, and at the same time, where $U_B \geq B_i$ holds for every even number i that satisfies $2 \leq i \leq k+1$, information is provided at every node from second to the k+1'th. In cases other than these, the game ends at the second ode without B providing information."

Then, let us examine A's decision at the first node. If information is not provided at the second node, A's payoff ends up with A_2. Since A_2 is smaller than A_1, which is the payoff of the case where information is not provided at the first node, A does not provide information at the first node. If information is provided at the second node, A's payoff ends up with U_A because of the characteristics of the subgame equilibrium after the second node. That is to say, A provides information if $U_A \geq A_1$ and does not if $U_A < A_1$, even if conditions of information provision exist in the subgame. This means that

A provides information only when conditions for information provision in the subgame are available, and at the same time, when $U_A \geq A_1$ holds. In cases other than this, the game ends without A providing information at the first node.

Combining $U_A \geq A_1$ and conditions for information provision in the subgame equilibrium, the equilibrium of the model n = k+1 would be as follows:

"Where $U_A \geq A_i$ holds for every odd number i that satisfies $1 \leq i \leq k+1$, and at the same time, where $U_B \geq B_i$ holds for every even number i that satisfies $1 \leq i \leq k+1$, information is provided at every node from the first to the k+1'th node. In cases other than this, the game ends immediately without A providing information at the first node."

This is equal to (5) in the body of the text with n = k+1 substituted into it. That is to say, if (5) is an equilibrium of the model where n = k, it is also an equilibrium of the model where n = k+1.

(v) From (i) to (iv) above, equilibrium of the model for $n \geq 1$ in general is as shown in (5).

The proof is done.

ACKNOWLEDGMENT

Author would like to thank scholars at RISTEX and Keio Business School for fruitful discussions.

REFERENCES

Grossman, G. M. and Helpman, E. (1991), *Innovation and Growth in the Global Economy*, MIT Press.

Kline, S. J. (1985), Innovation Is Not a Linear Process, *Research Management*, **28**(4), 36-45.

Kline, S. J. and Rosenberg, N. (1986), An Overview of Innovation, in Ralph Landau and Nathan Rosenberg (Ed.), *The Positive Sum Strategy*, National Academy Press.

Kline, Stephen Jay (1990), *Innovation Styles in Japan and the United States*, Stanford University.

Lee, C.-M. (2000), The Silicon Valley Habitat, in Lee Chong-Moon et al. (Eds.), *The Silicon Valley Edge*, Stanford University Press, 1-15.

Niwa, K. and Yamada, H. (1999), *Technology Management*, Seisansei Shuppan.

Roberts, R. M. (1989), *Serendipity*, John Wiley & Sons.

Rosenbloom, R. S. and Spencer, W. J. (1996), *Engines of Innovation*, Harvard Business School Press.

Rubinstein, A. (1982), Perfect Equilibrium in a Bargaining Model, *Econometrica*, **50**, 97-109.

Saxenian, AnnaLee (1996), *Regional Advantage*, 2nd ed., Harvard University Press.