Efficient P2P Knowledge Sharing: Performances and Incentives

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ABSTRACT

In this paper, we address the performance issue of Peer-to-Peer (P2P) knowledge sharing community based on two indices: the knowledge variety and the knowledge transfer. For each performance index, we examine Nash equilibrium and social equilibrium of knowledge contribution. While under-provision of knowledge contribution is a common phenomenon, the equilibrium results drawn from each criterion are significantly dissimilar. Results reveal the condition for the social optimality to sustain. Thus, in order to enhance the performance of knowledge sharing, incentive mechanisms are presented to realize an efficient knowledge sharing community.

Keywords: knowledge sharing, performance index, incentive mechanism, ash equilibrium, Social optimum.

1. INTRODUCTION

The concept of the knowledge sharing is becoming an emerging topic. Global operating firms especially capitalize this concept and take advantage of differences in labor costs, human capitals, and suitable production sites. For example, Toyota has opened up several subgroups of manufacturing sites in China and Southeast Asia to gain the labor advantage. Another example is that Microsoft has established numerous local headquarters in different countries to recruit the local human capitals and to convert their expertise into localized software product. Evidence has shown that organizations that are capable of transferring knowledge more effectively are more likely to sustain in the industry than those that have less capability of doing that (Argote, Beckman, and Epple, 1990).

Others view knowledge sharing or transfer should be incentive-aligned. Since the interest between the employees and employers does not always consistently work on the same direction, literatures has shown that incentive, the essence of motivation, plays a role in inducing employees to operate in the firm's interest. (Prendergast, 1999) The subtle question left to ponder will be how to carefully design a compensation contract, including options, discretionary bonuses, profit sharing, and efficient wages, and if the incentive needs to be immaterial only, material only, or rather a blended of both. (Semar, 2004) While material incentive are mostly in the form of direct monetary allowance, immaterial incentive is associated with working environment, contract extension, corporate resource assignment, etc.

Other than the incentive issue, knowledge sharing or knowledge transfer is the process, through which one group is affected by the experience of another (Argote, 1999). Intra-units are learning and benefiting from each other in order to speed up the production process or lower down the unnecessary labor costs. Transferring knowledge, whether at the individual, group, department, or division level is a usually laborious and time-consuming, and difficult task. Obviously, such transference needs a channel. Tsai (2001) claims the fact that prior to achieving access to a new knowledge, it needs to require a networking effect. With a great design of unit network, such channel will be a way to stimulate and support innovative activities. Moreover, in Swart and Kinni's work (2003), they suggest that for the success of the organization, knowledge be integrated between different units and be shared throughout. The rational is that the critical knowledge and skills may become localized within the project team as time passes (Wegner, 2000; Yanow, 1999).

The above studies have addressed the importance of knowledge sharing and incentive. Building the suitable environment and setting up the incentive will function to promote knowledge sharing or motivate staffs. In this paper, we focus on establishment of the knowledge sharing indices on a Peer-to-Peer (P2P) environment: knowledge variety and knowledge transfer. The proposed performance metrics are critically important and easily justified. Participants will benefit from the knowledge variety provided in the community. On the other hand, participants also benefit from more replicas of the same knowledge in a decentralized sharing environment because it is more likely a participant can get the knowledge from a closed participant. Consequently, the performance cost of knowledge can be improved. Through these indices, we may understand how parameters, two that will be proposed and each of which has its own appropriate quality, affect the sharing performance. We further introduce the concept of Nash equilibrium. Nash (1950) showed that in any finite game (i.e., a game in which the number of players n and the strategy sets $S_1, S_2, S_3, ..., S_n$ are all finite) there exists at least one Nash equilibrium. Note that Nash equilibrium is often generalized as a non-cooperative outcome. We make use of this concept, combine with another concept—the social optimum, generalized as a cooperative outcome, simply representing the summation of all individuals' payoffs, and incorporate the issue of incentive into the framework, which helps maintain the social optimum. Incentive, furthermore, can be analyzed in the context of public good provision. There are a few discussions regarding public goods, including Samuelson (1954), Olson (1965), Smith (1980), Cornes and Sandler (1984, 1985), and Andreoni (1985). Of these researchers, Samuelson and Olson are the classics references on the public good theory and the related topics in group size. Smith conducted his experiment to determine if the public good are subject to "free ride" in a voluntarily sharing environment. Cornes and Sandler, and Andreoni claimed that a consumer's utility depends not only on the aggregate amount of contribution, but also on his own contribution.

The idea that emerges in our study is the assignment of incentive. We attempt to establish the condition for the incentive that will mitigate "free ride" phenomenon and further make the social optimum sustainable. Our results show that knowledge contributions are quite different based on the knowledge variety and knowledge transfer performance criteria.

The remainder of this paper is organized as follows. In section 2, we discuss the knowledge indices. In section 3, we analyze the performance and incentive mechanism based on knowledge availability. In section 4, we re-examine the performance and incentive mechanism based on knowledge transfer. We provide a discussion in Section 4 and present the conclusion in Section 5.

2. PERFORMANCE INDEX OF KNOWLEDGE SHARING

When we evaluate a salesperson working performance, we often check on the number of orders he can get for the company. If the number of orders is massive, he may be evaluated as a great salesperson with an outstanding performance. Similarly, the knowledge sharing performance can be evaluated based on the knowledge varieties and the needed time for participants in the knowledge sharing community to retrieve certain knowledge. An efficient community may enlarge the knowledge pool and shorten the time for information retrieval. Suppose a knowledge worker has a need to retrieve a knowledge that is related to his work. If she acquires the relevant information in a short period of time and is satisfied with it, we say the knowledge sharing community has a distinguished performance in directing her to the correct knowledge. The knowledge sharing community has a bad performance, otherwise. Thus, we propose two simple but important factors that will affect the efficiency of knowledge sharing. They are the knowledge availability and the knowledge transfer. One the one hand, knowledge availability index reflects the possibility degree an (ad-hoc) requested knowledge can be found through the community, alternatively, we can interpret the index as the maximum number of knowledge varieties participants can retrieve from the community. On the other hand, knowledge transfer index represents the expected effort (e.g. delay time) for completing a knowledge transfer of certain type of knowledge request. The transfer effort can be indirectly measured according to the expected replicas of a homogeneous knowledge provided in the community since the performance can be improved by selecting a better partner to conduct the knowledge transfer activity. We conduct the analysis under self-enforced and efficient knowledge sharing configurations according to these two performance considerations and suggest the incentive mechanisms for aligning the objective of individual participant and the organization.

3. KNOWLEDGE AVAILABILITY (VARIETY)

Before we make knowledge communicated in the community, it is important to understand that the formation of knowledge involves difficulties and the nature of knowledge is structural. There are various attempts to describe "knowledge" as the term "structure." Rauch-Hindin (1988) firstly noted the presence of structure in knowledge. Then Gaines, Rappaport, and Shaw (1992) further defined four types of knowledge structure: informal, structured, formal, and computational knowledge. When the information becomes knowledge and pooled into the community, we are concerned with the sharing performance. In this section, we propose that the knowledge variety is the factor that will affect the performance for knowledge sharing in the community. We will make the following assumptions. At first, we assume that the participant will receive the value of v_i from process of the successful sharing of certain knowledge. She will, of course, incur the cost of c_i if she shares certain knowledge. Secondly, more knowledge variety is better for the knowledge sharing environment. More varieties mean that the difficulty level for requesting a random type of knowledge will be reduced and it becomes easier for any participant to gain that random type of knowledge in the community. Then, let M_0 denote the number of elements in the knowledge domain and i be the participant who provides a random type of knowledge. If each knowledge variety has the same popularity, then we assume x_i is the probability that participant i shares an arbitrary file. We further assume $0 \le c_i / v_i \le 1$, which is the cos-benefit ratio of knowledge sharing. Since no one is willing to pay more than what she receives, thus, the ratio of c_i / v_i, which does not exceed one, makes intuitively sense. In the context of reliability, we denote $H = 1 - \prod_{i=1}^{n}(1-x_i)$ as a probability that the knowledge sharing process is successful in the community. Multiplied by the maximum number of knowledge elements M_0, this gives the expected number of knowledge varieties, M, the following expression

$$M(x_1, x_2, \cdots, x_n) = HM_0 = \left(1 - \prod_{i=1}^{n}(1-x_i)\right)M_0 .$$

Furthermore, the expected payoff to agent i is taken to be

$$U_i = v_i M - c_i x_i M_0 = v_i\left(1 - \prod_{i=1}^{n}(1-x_i)\right)M_0 - c_i x_i M_0 \tag{1}$$

3.1. Nash Equilibrium (Self-Enforced Community)

In this section, we examine the outcome where single participant chooses effort unilaterally.

Equation (1) can be rewritten as

$$U_i = v_i\left(1 - \prod_{i=1}^{n}(1-x_i)\right)M_0 + \left(v_i \prod_{j\neq i}^{n}(1-x_j^*) - c_i\right)x_i M_0 .$$

The above equation represents a non-cooperative utility function. The individual objective is to maximize this utility function subject to the following best response knowledge sharing function given to the participant i, which is

$$x_i^* \begin{cases} = 1 & \text{if } \prod_{j\neq i}^{n}(1-x_j^*) > c_i / v_i \\ \in [0,1] & \text{if } \prod_{j\neq i}^{n}(1-x_j^*) = c_i / v_i \\ = 0 & \text{if } \prod_{j\neq i}^{n}(1-x_j^*) < c_i / v_i \end{cases}$$

See Fig 1 below for how participant i respond according to other participants' move.

Whether the participant i's best response is to share or not share depends solely on where $\prod_{j\neq i}^{n}(1-x_j^*)$ lies. Given $\prod_{j\neq i}^{n}(1-x_j^*)$ lies above $\frac{c_i}{v_i}$, the participant i must share in order to make the sharing community successful. In contrast, given $\prod_{j\neq i}^{n}(1-x_j^*)$ lies below $\frac{c_i}{v_i}$, the participant i may choose not to share. The necessary condition for a knowledge sharing community to emerge is $0 < H < 1$. If the participant i contributes, we have $0 < x_i < 1$; that is, the equilibrium knowledge sharing level of each participant can be drawn by solving the following equations simultaneously.

$$\prod_{j\neq i}^{n}(1-x_j) = c_i / v_i,\ \forall i \in \{1, \cdots, n\}$$

After some mathematic simplifications, we obtain the knowledge availability equilibrium

$$H^{N^*} = 1 - \left(\prod_{i=1}^{n}\frac{c_i}{v_i}\right)^{1/(n-1)} \tag{2}$$

and the knowledge sharing level of participant is

$$x_i^{N^*} = 1 - \frac{v_i}{c_i}\left(\prod_{i=1}^{n}\frac{c_i}{v_i}\right)^{1/(n-1)} \tag{3}$$

Under Nash equilibrium, Equation (2) is the optimum probability that the knowledge sharing community will work. In other words, it indicates the optimum probability that a participant gives a random type of knowledge, needed by the members in the knowledge sharing community. Equation (3) is the optimum probability that an arbitrary given file is shared by a participant. In practice, this probability needs to exhibit an upward trend as the number of participants who possess a random type of knowledge increases. The number of knowledge varieties in equilibrium is $M^{N^*} = \left(1 - \left(\prod_{i=1}^{n}\frac{c_i}{v_i}\right)^{1/(n-1)}\right)M_0$. We will compare this probability with the probability under the social optimum level.

3.2. Social Optimum (Efficient Community)

We perform similar calculations in this section so as to derive the socially optimal content availability H^{W^*} in the community and individual knowledge sharing level $x_i^{W^*}$. The difference between the social optimum and Nash equilibrium is that while Nash equilibrium focuses on the unilateral optimization, the social optimum dwells its focus on the coordinated effort. Precisely, Equation (1) needs to be adjusted so as to maximize social benefits subtracted by social costs.

$$U_w = \sum_{i=1}^{n} U_i = \Sigma_{i=1}^{n} v_i\left(1 - \Pi_{i=1}^{n}(1-x_i)\right)M_0 - \Sigma_{i=1}^{n} c_i x_i M_0 \tag{4}$$

Similarly, the socially optimal individual knowledge sharing level is given by solving the following equations simultaneously.

$$\Pi_{j\neq i}^{n}\left(1-x_j^*\right) = \frac{c_i}{\Sigma_{i=1}^{n} v_i},\ \forall i \in \{1, \cdots, n\} \tag{5}$$

Finally, the optimality functions for both H^{W^*} and $x_i^{W^*}$ are as follows:

$$H^{W^*} = 1 - \left(\prod_{i=1}^{n} \frac{c_i}{\sum_{i=1}^{n} v_i} \right)^{1/(n-1)} \tag{6}$$

$$x_i^{W^*} = 1 - \frac{\sum_{i=1}^{n} v_i}{c_i} \left(\prod_{i=1}^{n} \frac{c_i}{\sum_{i=1}^{n} v_i} \right)^{1/(n-1)} \tag{7}$$

Socially optimal number of knowledge varieties is

$$M^{W^*} = \left(1 - \left(\prod_{i=1}^{n} \frac{c_i}{\sum_{i=1}^{n} v_i} \right)^{1/(n-1)} \right) M_0 .$$

Investigating these two functions, we realize that $x_i^{W^*} \geq x_i^{N^*}$ and $M^{W^*} \geq M^{N^*}$. We turn to the related interpretation of public good. In a centralized environment developed in our model, $x_i^{W^*} \geq x_i^{N^*}$ reflects the fact that pure public goods would be undersupplied by voluntary contributions and that there exists an incentive for a participant to free ride since no one can be excluded from the benefits of public good. By definition, free-ride means that contributing less than his marginal valuation to the cost of the public good.

In an extreme case, when $x_i^{N^*} \cong 0$, non-provision of public goods becomes a consequence of the strong free riders phenomena.(Brubaker, 1975) However, any level below $x_i^{N^*}$ suggests the sub-optimal quantities of public goods.

3.3. Socially Optimal Compensation

Inconsistent interest between personal level and social level contributes to the difference in effort level. Under Nash condition, the participant *i* cares about personal interest only and maximizes it, whereas in the social optimum situation, the sharing effort is underprovided. However, a proper amount of compensation makes the participant *i* not play Nash and still exert the sharing effort even in the social situation.

For simplicity, the sharing community is divided into two categories: one group consisting of only one participant, *i*, the other group consisting of all other participants. (e.g. $\sum_{j \neq i}^{n} \textit{paticiapnt } j$) The proposed incentive framework is a treatment for the participant *i* only and does not have any power to predict the amount of incentive requested by any other participants in the other category. Two assumptions are subtle. At first, the incentive will make participant who receives it share. Secondly, it is a possibility that other participants who do not receive any compensation may free ride. The following is the proposed framework.

Proposition 1: *The social level of effort can be induced and be optimally sustainable when the incentive compensation,* r_i, *equals* $\frac{c_i \sum_{j \neq i}^{n} v_j}{\sum_{j=1}^{n} v_j}$ *for the participant i.*

Proof. At first, let U', denoted as the compensation function, entails an incentive term, $r_i x_i M_0$. This function and Equation (1) are very much the same with exception of $r_i x_i M_0$. Our objective is to derive the value of this incentive.

$$U' = v_i \cdot \left(1 - \prod_{i=1}^{n} (1 - x_i)\right) M_0 - c_i x_i M_0 + r_i x_i M_0 \tag{8}$$

The best response knowledge sharing function of participant *i* is given by the following expression:

$$\left(v_i \prod_{j \neq i}^{n} \left(1 - x_j^*\right) - c_i\right) + r_i = 0 \tag{9}$$

Equation (5) can be rewritten as

$$\left(v_i \prod_{j \neq i}^{n} \left(1 - x_j^*\right) - c_i\right) + \sum_{j \neq i}^{n} v_j \prod_{j \neq i}^{n} \left(1 - x_j^*\right) = 0 \tag{10}$$

Investigating Equation (9) and Equation (10), we understand that

$$r_i = \sum_{j \neq i}^{n} v_j \prod_{j \neq i}^{n} \left(1 - x_j^*\right).$$

Substituting $\prod_{j \neq i}^{n} \left(1 - x_j^*\right) = \frac{c_i}{\sum_{i=1}^{n} v_i}$ into r_i, r_i becomes the following expression:

$$r_i^{W^*} = \sum_{i=1}^{n} v_i \prod_{j \neq i}^{n} \left(1 - x_j^{W^*}\right) = \frac{c_i \sum_{j \neq i}^{n} v_j}{\sum_{i=1}^{n} v_i} \quad \square \tag{11}$$

Equation (11) indicates a unique value of the incentive, which is a minimally required compensation for the participant *i* in the knowledge sharing community. Moreover, Equation (11) suggests a redistribution of wealth. Varian (1986) studies this topic and stated that any change in the wealth distribution that increases the aggregate wealth of current contributors will necessarily increase the equilibrium supply of the public good. This viewpoint corresponds to our result. The amount of incentive implies an increase in supply of public good. If this amount of incentive is in its optimal condition, then it is immediate that the supply of public good is also in its optimality.

4. KNOWLEDGE TRANSFER (REPLICA)

In previous section, we have examined the knowledge sharing community configurations based on knowledge variety. We further introduce another performance index, the knowledge transfer. The performance of knowledge transfer is closely associated with the number of replicas of a given knowledge in the community. Different from the knowledge variety, the knowledge replica is defined as coexistence of homogeneous knowledge. In the knowledge sharing community, we need some identical knowledge to exist because this helps participants more easily gain certain type of knowledge from a "closer" community member. Since x_i is the probability that the participant *i* shares certain knowledge, we denote the expected number of replicas of a type of knowledge in the community as $R(x_1, x_2, \cdots, x_n) = \sum_{i=1}^{n} x_i$. We further assume that the transfer effort (e.g. delay) between any two participants is a random variable with value drawn from a transmission delay density function. Participants always retrieve knowledge from a community member with a minimum transfer effort. Denote the expected minimum transfer effort among *k* community members by $T(k)$. Using order statistics, we have:

$$T(k) = \int_0^{\infty} t \cdot k \cdot (1 - F(t))^{k-1} \cdot f(t) \cdot dt ,$$

where *f*(*t*) and *F*(*t*) are the PDF and CDF for the transfer effort. In this paper, we analyze the community configuration based on uniform distribution $U[0, T_0]$, where T_0 is the upper bound of transfer effort. Thus, given individual knowledge sharing level $(x_1, x_2, \cdots, x_n)$, the expected transfer effort is:

$$T(R) = \left(\sum_{i=1}^{n} x_i + 1\right)^{-1} T_0 .$$

Lastly, we denote the value of a transfers knowledge as v_i, and assume the cost of transfer effort (e.g. delay cost) and sharing cost for a knowledge are β_i and c_i respectively. The utility function is defined as follows:

$$U_i = v_i - \beta_i T(R) - c_i x_i = v_i - \beta_i \left(\sum_{i=1}^{n} x_i + 1\right)^{-1} T_0 - c_i x_i \tag{12}$$

4.1. Nash Equilibrium (Self-Enforced Community)

Following similar approach, individual's self-selected knowledge sharing level can be obtained by solving the first-order conditions simultaneously:

$$\frac{\partial U_i}{\partial x_i} = \beta_i T_0 \left(x_i + \sum_{j \neq i}^{n} x_{j \neq i}^{*} + 1\right)^{-2} - c_i \leq 0, \forall i$$

The best response knowledge sharing function for participant *i* is

$$x_i^{N^*} = \max\left\{ \sqrt{\frac{\beta_i T_0}{c_i}} - \left(\sum_{j \neq i}^{n} x_{j \neq i}^{*} + 1\right), 0 \right\} \tag{13}$$

Thus, the expected number of knowledge replicas of a type of knowledge is

$$R^{N^*}(x_1, x_2, \cdots, x_n) = \sum_{i=1}^{n} x_i^{N^*} = \max_i\{\sqrt{\frac{\beta_i T_0}{c_i}} - 1\} \tag{14}$$

We can easily find that the self-selected knowledge sharing level is

$$x_i^{N^*} = \begin{cases} \sqrt{\dfrac{\beta_i T_0}{c_i}} - 1 & \text{if } i = \arg\max_j \{\beta_j / c_j\} \\ 0 & \text{otherwise} \end{cases}$$

For a self-formed knowledge sharing community, only the participant with the maximum ratio of transfer effort cost (e.g. time value) to sharing cost contributes knowledge.

4.2. Social Optimum (Efficient Community)

We are concerned with the social optimum so we sum up the utility from all participants and get the following expression:

$$W = \sum_{i=1}^{n} U_i = \sum_{i=1}^{n}\left(v_i - \beta_i \left(\sum_{i=1}^{n} x_i + 1\right)^{-1} T_0 - c_i \cdot x_i\right) \tag{15}$$

With first-order condition:

$$\frac{\partial W}{\partial x_i} = \Sigma_{i=1}^{n} \beta_i T_0 \left(\sum_{i=1}^{n} x_i + 1\right)^{-2} \le c_i, \forall i \tag{16}$$

Socially optimal expected number of replicas of a type of knowledge is:

$$R^{W^*}(x_1, x_2, \cdots, x_n) = \sum_{i=1}^{n} x_i^{W^*} = \max_i\{\sqrt{\frac{\Sigma_{i=1}^{n}\beta_i T_0}{c_i}} - 1\} \tag{17}$$

Finally, the socially optimal individual knowledge sharing level is derived:

$$x_i^{W^*} = \begin{cases} \sqrt{\dfrac{\Sigma_{i=1}^{n}\beta_i T_0}{c_i}} - 1 & \text{if } i = \arg\min_j \{c_j\} \\ 0 & \text{otherwise} \end{cases}$$

For an efficient knowledge sharing community, only the participant with the minimum sharing cost is required to contribute knowledge.

Investigating Equations (14) and (17), we realize that $R^{W^*} \ge R^{N^*}$. This finding suggests that more knowledge replicas increase the knowledge density in the sharing community and shorten the transferring distance among participants. For such shortened distance, the transfer of the knowledge may become easier.

4.3. Socially Optimal Compensation

In this section, we return to consider the optimal incentive to induce the sharing effort in social level for the participant *i*. See the following framework.

Proposition 2: *The social level of effort for the participant i who have the minimum sharing cost can be induced and be optimally sustainable when the incentive compensation,* r_i*, equals* $\Sigma_{j\ne i}^{n}\beta_j T_0 \left(\sqrt{\dfrac{\Sigma_{i=1}^{n}\beta_i T_0}{\min_i \{c_i\}}}\right)^{-2}$.

Proof. Similar to the proof in **Proposition 1**, we, at first, impose an incentive term r_i on Equation (12). Thus, it becomes

$$U_i' = v_i - \beta_i \left(\sum_{i=1}^{n} x_i + 1\right)^{-1} T_0 - c_i x_i + r_i x_i \tag{18}$$

The first-order condition for Equation (18) is

$$\frac{\partial U_i'}{\partial x_i} = \beta_i T_0 \left(x_i + \sum_{j\ne i}^{n} x_j^* + 1\right)^{-2} - c_i + r_i = 0 \tag{19}$$

Secondly, we rewrite Equation (16)

$$\left(\beta_i T_0 \left(\sum_{i=1}^{n} x_i^* + 1\right)^{-2} - c_i\right) + \Sigma_{j\ne i}^{n}\beta_j T_0 \left(\sum_{i=1}^{n} x_i^* + 1\right)^{-2} = 0 \tag{20}$$

Investigating Equation (19) and Equation (20), we understand that

$$r_i^{W^*} = \Sigma_{j\ne i}^{n}\beta_j T_0 \left(\sum_{i=1}^{n} x_i^* + 1\right)^{-2} = \Sigma_{j\ne i}^{n}\beta_j T_0 \left(\sqrt{\frac{\Sigma_{i=1}^{n}\beta_i T_0}{\min_i \{c_i\}}}\right)^{-2} \quad \square,$$

which is exactly the incentive condition under which the participant *i* needs to be compensated to exert the social optimal level of effort. For our purposes, the incentive mechanisms in this section and in Section 3.3 affect the participant *i* only and do not apply to any other knowledge contributors. This mechanism also reveals a compensating relationship between the participant *i* and the operator in the sharing community. We see that the community in general could benefit by the participant *i*'s contribution. The participant *i* receives the compensation $r_i^{W^*}$ in exchange.

4. DISCUSSION

There is more to the issue of incentive than just the Nash and social optimum configurations. Consider the following prisoner's dilemma. In Prisoner's dilemma, each player has two strategies: confess (or fink) and not confess (or be mum). Playing Fink is the dominated strategy for both players, then (Fink, Fink) is the unique solution to this game, a so-called Nash equilibrium. Let's classify it as a non-cooperative outcome and compare it with another outcome (Mum, Mum), classified as a cooperative outcome. Even though the cooperative outcome allows both parties to gain the most benefits, it is relatively unstable because either player has an incentive to deviate against each other to gain the free charge. Thus, the non-cooperative outcome of (Fink, Fink) will be an equilibrium, at which no one has an incentive to deviate.

Our model is really an extension and application of the prisoner's dilemma. Owing to the insight derived from the prisoner's dilemma, there is no cooperation in its one-period design. Cooperation cannot be maintained in the one-period game because there are no future periods to impose punishment on the behavior which deviates from a cooperative solution. (Pecorino, 1999) Thus, to quantitatively determine the amount of incentive in our model is indeed an initiative. This amount of incentive will guarantee that for a particular participant in the knowledge sharing community, he will achieve the cooperative outcome and maintain the cooperation as equilibrium.

Nevertheless, our model is still a one-period game and cannot be generalized to predict the equilibrium in the context of infinitely repeated game. Other than the assignment of incentive, what conditions will make the game that is played infinite times sustainable? Or, stated differently, what conditions will affect participants' sharing decision? What is the setting of this super game? And, how will all other participants, not just a particular participant, be facilitated to achieve the cooperative outcome? Those questions remain the core focus in the next research stage and will help to devise a cooperative mechanism.

5. CONCLUSION

This paper allows us to draw the conclusion in two ways. At first, we obtained the relationship between the knowledge sharing performance and factors that might affect the performance. Interestingly, as the numbers of varieties and replicas go upward, there is a positive effect in the knowledge sharing. Thus, in order for knowledge sharing to be successful, the amount of knowledge has to be both extensive and intensive. Secondly, we proved that a proper incentive assignment may enhance the knowledge sharing. This may be seen as a social optimum condition if it needs to be achieved.

We must emphasize that it remains possible, of course, that there are other undefined factors other than knowledge variety and knowledge replica that may affect the sharing behavior. Thus, the methodological design in this paper limits the interpretations. Future research is needed on the implications for knowledge sharing in organizations. For example, suppose new member who want to search for some specific knowledge, how may the searching time vary under variety-intensive condition? In addition, categorization of knowledge according to its properties may become another factor to affect the knowledge sharing performance. The rationale is that item that is always properly stored means that it will be found easily.

REFERENCES

Argote, L., Beckman, S.L., & Epple, D., "The persistence and transfer of learning in industrial settings," Management Science, 36, 140–154 (1990)

Argote, L. "Organizational learning: Creating, retaining, and transferring knowledge," Boston: Kluwer Academic, (1999)

Argote, L., & Ingram, P., "Knowledge transfer: A basis for competitive advantage in firms," Organizational Behavior and Human Decision Processes, 82, No.1, 150-169, (2000)

Andreoni, J., "Privately provided public goods in a large economy: The limits of altruism," Journal of Public Economics, 35(1), 57-73, (1988)

Brubaker, E., "Free ride, free revelation, or golden rule?," Journal of Law Economics, 18, 147-161, (1975)

Bergstrom, T., Blume, L., Varian, H., "On the private provision of public goods," Journal of Public Economics, 29, 25-49, (1986)

Chow, P.K., Yeung, D.S., "A Multidimensional knowledge structure," Experts Systems with Applications, 9, No. 2, 177–187 (1995)

Cornes, R., and Sandler, T., "Easy riders, joint production, and public goods," Economic Journal, 94, (1985)

Gaines, B.R., Rappaport, A.T., & Shaw, M.L.G., "Combining paradigms in knowledge engineering," Data & Knowledge Engineering, 9, 1-18

Kwan, M.M., & Cheung, P.K., "The knowledge transfer process: From the field studies to technology development," Journal of Database Management, 17(1), 16 – 32 (2006).

Nash, J., "Equilibrium points in n-person games," Proceedings of the National Academy of Science, 36:48-49 (1950)

Prendergast, C., "The provision of incentive in firms," Journal of Economic Literature, Vol. XXXVII, 7-63, (1999).

Pecorino, P., "The effect of group size on public good provision in a repeated game setting," Journal of Public Economics, 72, 121-134 (1999)

Rauch-Hindin, W. B., "A guide to commercial artificial intelligence: Fundamentals and real-world applications," Eagle0wood Cliffs, NJ: Prentice-Hall, (1988)

Semar, W., "Incentive systems in knowledge management to support cooperative distributed forms of creating and acquiring knowledge," Proceeding of the International Conference on Information and Knowledge Engineering, Las Vegas: CSREA Press, 406-411 (2004)

Smith, Vernon L., "Experiments with a decentralized mechanism for public good decisions," The American Economic Review, Vol. 70, No. 4, 584-599, (1980)

Swart, J. and Kinnie, N., "Sharing knowledge in knowledge-intensive firms," Human Resource Management Journal, 13, 2, 60-76 (2003)

Tsai, W., "Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance," Academy of Management Journal, Vol. 44, No. 5, 996–1004 (2001)

Varian, H.R., "System reliability and free riding," (2004)

Wenger, E., "Communities of practice and social learning systems," Organization, 7:2, 225-246, (2000).

Yanow, D., "The languages of "organizational learning": a palimpsest of terms," Proceedings from the Third International Conference on Organizational Learning, June, 1075-1086, (1999)