Knowledge Integration: A Public Goods Approach Under Asymmetric Information

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ABSTRACT
Knowledge integration is one of the keys to e-business which have more competitive advantage than traditional organizations. However, building knowledge management system from technology-oriented and user viewpoint is insufficient. Because of the effect of free-riding, the benefit of knowledge integration can't be linked to group size in direct proportion. This paper examines how the total effective level of effort persons exert vary with individual belief about knowledge level, group size, and their cost-knowledge level ratios. This study discusses the relation among these factors and proposes solutions to vanish the effect of free-riding under asymmetric information.

Keywords: Knowledge integration, public goods, asymmetric information

1. INTRODUCTION
In the past few years, knowledge management had mushroomed all over the industrials. According to the framework addressed by Alavi et al. (2001), "knowledge process" is classified into four fundamental elements: (1) construction, (2) storage/retrieval, (3) transfer, and (4) application. One research question they proposed is how to implement effectively knowledge transfer. In recent work, Lin et al. (2005) have proposed a sender-receiver framework for investigating knowledge transfer under asymmetric information. They view knowledge as goods traded in a knowledge market and one of their most significant research contributions is to apply a signaling mechanism to overcome 'adverse selection problem', which is a common phenomenon arising in knowledge sharing that means inability manager is unable to differentiate between the qualities of knowledge under incomplete-information.

Successful knowledge management can be attributed to ability, motivation, and opportunity (Argote et al. 2003). Ability is a talent but can be enhanced by training (Nadler et al. 2003). The position of ability should be identified so as to make it more valuable. Thus, opportunity, such as an organization or informal networks, establishes an invisible multidirectional channel to save acquiring and search cost by reducing distance (Borgatti and Cross 2003, Hansen 1999, McEvily and Zaheer 1999, Reagans and Zuckerman 2001, Uzzi and Lancaster 2003). However, knowledge transfer will be inefficient if members of the organization utilize internal knowledge without any reward. (Menon and Pfeffer 2003). Hence, in addition to ability and opportunity, the organization should provide members with motivation to take part in the knowledge management process (Argote et al. 2003).

Another major research question is what incentive makes persons contribute and share their knowledge truthfully. Although organizational knowledge can be conveniently stored in various component forms, including electronic documentation, database, and even expert system (Tan et al. 1998), many factors limit the success of knowledge storage. One of the barriers is that employees lack time to transform their knowledge into reusable component forms (Cranfield University 1998; KPMG 1998b; Glazer 1998). Another barrier is their organizational culture without a rewarded mechanism for exerting such effort (Brown and Duguid 1998; Cranfield University 1998; KPMG 1998b).

Because knowledge sharing is one of the most important aims in most knowledge management projects, many managers seek an efficient way to make their employees contribute their knowledge without reservation, not hiding what they had learned. In d'Aspremont et al. (1998), knowledge is treated as public goods for studying sharing knowledge and development efforts on R&D agreements and research joint ventures. They have considered a situation where one cannot identify a 'most knowledgeable' partner and proposed a balanced contract arrangement based on a two stage game which leads the cooperative activities to a first best solution.

"Free-riding" is a common effect when a group carries out knowledge sharing and all participants could consume the public benefit. This is because the provision of public goods generates an externality that all participants benefit from others who provide public goods. Hence, individuals' behaviors may tend to reserve their effort, resulting in the decrease of the level of the public good. The concept of public goods is also conveniently applied to other disciplines characterized by non-rivalness and non-excludability, such as peer-to-peer system, information security, and so on. Varian (2004) examined how system reliability varied with three prototypical cases: total effort, weakest link, and best shot. In the case of total effort under complete-information, his research result shows that system reliability is determined by the agent with the highest benefit-cost ratio. This result is similar to the work of Bhattacharya et al. (1992) which suggests that the most intelligent agent's knowledge is the only useful input for efficient development effort when individual knowledge levels are revealed.

To help employees share their best findings and management experiences, a large number of companies put themselves to the great expense of hiring consultants to set up IT-based applications, gathering and retrieving their useful knowledge. Ba et al. (2001), however, point out that building knowledge management system from software engineering and user acceptance perspectives is insufficient. Under circumstances without incentive, a manager is difficult to entice her peers and subordinates to contribute their individual knowledge into the knowledge management system.

As in Antoniadis et al (2004), we consider knowledge a cumulative public goods like files their work handles. Because our model treats in this paper the case where there are only two types of knowledge, this distinction makes ours less complicated to yield analytical solution under incomplete-information. The heart of this study is to establish an incentive mechanism depended on different knowledge types under incomplete-information, also known as screening, or truth telling. We present the model in section 2 and enhance this model by adding incomplete-information in section 3. A screening mechanism is introduced and detailed in section 4. Finally, we give a numerical example and conclude this paper in section 5 and 6.

2. A MODEL OF KNOWLEDGE INTEGRATION
Consider a knowledge integration model for n participants. These participants want to cooperate to get certain epistemic work done efficiently and share the public benefit, such as product development, technology innovation, or knowledge sharing. In order to simplify analysis process, Lin et al. (2005) denote the expected value of a participant's knowledge as either K_H (high level) or K_L (low level), where $K_H > K_L > 0$. We follow the same notations and call a person with high knowledge level a high type participant, and one with low knowledge level a low type participant. Similarly, we define C_H and C_L as the cost of exerting effort to a high type participant and low type one, respectively. We assume $C_H < C_L$ for a high type participant is efficient than low type one. This assumption means that the cost is an increasing linear function, the argument of which is the level of effort, and knowledge of higher level can reduce more expenses than that of inferior level under exerting the same effort.

In this model of complete-information version, each participant decides on x_i, the quantity of effort she exerts, where $x_i \geq 0$. In this paper we assume that each participant is risk neutral and effort is an observable variable, such as work hours, the frequency of proposals, or the cited rate of individual submitted report. The total effective level of effort and cooperative benefit is respectively defined as $Q = \sum K_i x_i$ and $f(Q)$, where the cooperative benefit function $f(.) \geq 0$ is assumed to be continuously differentiable, increasing, and concave in its argument. Then, the payoff of participant i is $f(Q) - c_i x_i$. For participant i, solving the first-order condition for participant i's payoff and defining $G(.)$ as an inverse function of $f'(.)$ yields:

$$x_i^* = \max\left\{\frac{1}{K_i} G\left(\frac{c_i}{K_i}\right) - \frac{1}{K_i}\sum_{j \neq i} K_j x_j^*, 0\right\}. \tag{1}$$

Each participant's strategy shows that when marginal public benefit is not greater than marginal private cost, they will free ride on the others. Thus, participants with highest knowledge-cost ratio determine a Nash equilibrium and the others free ride on the participants. This also means that when the number of participants with highest knowledge-cost ratio is greater than one, the number of Nash equilibrium outcomes will be infinite. Because concentrating on the total effective effort, we use asymmetric Nash equilibrium outcome directly for convenient.

$$\frac{1}{mK_H} G\left(\frac{c_H}{K_H}\right),$$

therefore, is the symmetric Nash equilibrium outcome we derive from (1) if there exists at least one high type participant in the group, where m is the number of high type participants. By considering a situation where all participants are low type ones, we have

total effective effort

$$Q^* = \begin{cases} G\left(\frac{c_H}{K_H}\right) & \text{if } \exists K_i \neq K_L \\ G\left(\frac{c_L}{K_L}\right) & \text{if } K_i = K_L, \forall i \end{cases}. \tag{2}$$

Our first proposition summarizes the above observations.

Proposition 1. In complete-information case (the knowledge type of each participant is public information),

(a) the low type participants always free ride on the high type participants, and
(b) for any group size, overall knowledge integration level, i.e., Q^*, is the same except that all participants are low type ones.

If nature determines the probability that $K_i = K_H$ is θ, in complete-information case the expected total effective level of effort they exert under given condition is

$$E\left[Q^*\right] = (1-\text{q})^n G\left(\frac{c_L}{K_L}\right) + \left(1-(1-\text{q})^n\right) G\left(\frac{c_H}{K_H}\right). \tag{3}$$

We now consider a scenario where knowledge integration is initiated by an all-powerful leader who has complete and perfect information about all participants' parameters. The leader, therefore, can stipulate the effort each participant should exert to maximize the social welfare:

$$\underset{x_1, x_2, \ldots, x_n}{Maximize} \quad W = \sum_{i=1}^{n} f(Q) - c_i x_i. \tag{4}$$

By first-order condition, this program would be optimal allocation if $\frac{\partial W}{\partial x_i} = nK_i f'(Q) - c_i \leq 0$ holds for each participant i. These inequalities mean that individual contribution levels have to maximize the total value of the group less the total cost incurred by the participants. Thus, from $f'(Q) \leq \frac{c_i}{nK_i}$ and $\frac{K_H}{c_H} > \frac{K_L}{c_L}$, we derive the socially optimal total effective level of effort:

$$Q_s^* = \begin{cases} G\left(\frac{c_H}{nK_H}\right) & \text{if } \exists K_i \neq K_L \\ G\left(\frac{c_L}{nK_L}\right) & \text{if } K_i = K_L, \forall i \end{cases}. \tag{5}$$

The above observations suggest that based on the viewpoint of arbitrary, a compulsive policy should force participants carry out $x^*(K_H) = \frac{1}{mK_H} G\left(\frac{c_H}{nK_H}\right)$ and $x^*(K_L) = 0$ if given m high type participants, where $m \geq 1$; otherwise, $x^*(K_L) = \frac{1}{nK_L} G\left(\frac{c_L}{nK_L}\right)$.

Proposition 2. In complete-information, the achievement of social welfare implies that

(a) socially total effort is absorbed by all high type participants if there exists at least one high type participant in the group, and
(b) low type participants' selfish shirking behaviors are allowable due to lacking of competitive advantage, unless all persons are low type participants.

Furthermore, we consider a situation where each participant can determine whether to join the group or not. In fact, a high type participant might receive a negative payoff under the arrangement of social welfare. If a high type participant's payoff is negative and the cooperative activity is devoid of a reasonable compensation mechanism, she will leave the group. Hence, the compensation mechanism is necessary for the achievement of social welfare if all participants have liberty to determine whether to join or leave.

Because social welfare, $W = \sum_{i=1}^{n}\left(f(Q) - c_i x_i\right)$, can be decomposed into $f(Q) - c_i x_i$ and $\sum_{j \neq i}^{n}\left(f(Q) - c_j x_j\right)$, we could derive $\frac{\partial}{\partial x_i}\left(f(Q) - c_i x_i\right)$ and $\frac{\partial}{\partial x_i}\sum_{j \neq i}^{n}\left(f(Q) - c_j x_j\right)$ after differentiating both expressions with respect to x_i. Hence, differentiating social welfare with respect to x_i yields:

$$\frac{\partial W}{\partial x_i} = \frac{\partial}{\partial x_i}\left(f(Q) - c_i x_i\right) + \frac{\partial}{\partial x_i}\sum_{j \neq i}^{n}\left(f(Q)\right) \tag{6}$$

Because each participant's individual payoff is to maximize $f(Q) - c_i x_i$, $\frac{\partial}{\partial x_i}\left(f(Q) - c_i x_i\right) = 0$ is the first-order condition to this problem which is the same as the former part of $\frac{\partial W}{\partial x_i}$. Hence, the externalities can be measured by $\frac{\partial}{\partial x_i}\sum_{j \neq i}^{n}\left(f(Q)\right)$ for participant i. Solving it yields:

$$\frac{\partial}{\partial x_i}\sum_{j \neq i}^{n}\left(f(Q)\right) = (n-1) f'(Q) K_i \tag{7}$$

Thus, the appropriate socially optimal compensation paid for a high type participant is:

$$p_H = (n-1) f'\left(Q_s^*\right) K_H = \left(\frac{n-1}{n}\right) c_H. \tag{8}$$

Since low type participants free ride on social welfare unless all persons are low type participants, the appropriate socially optimal compensation for them is:

$$p_L = \begin{cases} 0 & \text{if } \exists K_i \neq K_L \\ \left(\dfrac{n-1}{n}\right) c_L & \text{if } K_i = K_L, \forall i \end{cases} . \qquad (9)$$

Because in social welfare the externalities increase with the group size, the subsidy paid to participants also increases with the number of attendants.

Proposition 3. In the complete-information case, if all participants are paid p_H or p_L based on their types, Nash equilibrium outcomes achieve the socially optimal level of effort.

3. KNOWLEDGE INTEGRATION UNDER ASYMMETRIC INFORMATION

In this section we consider this model of incomplete-information version. Assuming each participant has private information about her knowledge type and all participants' knowledge types are independent. Let $x_i^*(K_H)$ and $x_i^*(K_L)$ denote participant *i*'s effort as a function of her knowledge level. Each participant knows that her coworkers' knowledge level is high with probability θ and anticipates that their effort would be $x_i^*(K_H)$ or $x_i^*(K_L)$, depending on their knowledge level. This implies that each participant's expected effective level of effort is:

$$\theta K_H x_j^*(K_H) + (1-\theta) K_L x_j^*(K_L) . \qquad (10)$$

Thus, based on individual knowledge level, participant *i* chooses $x_i^*(K_i)$ to maximize her payoff as follows:

$$\max_{x_i(K_i)} U_i(K_i) = f\left(K_i x_i + \sum_{j\neq i} \theta K_H x_j^*(K_H) + (1-\theta) K_L x_j^*(K_L)\right) - c_i x_i . \qquad (11)$$

Solving the first-order condition for (10) yields:

$$x_i^*(K_H) = \frac{1}{K_H} G\left(\frac{c_H}{K_H}\right) - \sum_{j\neq i} \theta x_j^*(K_H) - (1-\theta)\frac{K_L}{K_H} x_j^*(K_L) \qquad (12)$$

and

$$x_i^*(K_L) = \frac{1}{K_L} G\left(\frac{c_L}{K_L}\right) - \sum_{j\neq i} \theta \frac{K_H}{K_L} x_j^*(K_H) - (1-\theta) x_j^*(K_L) . \qquad (13)$$

In a separating strategy, we let $x_i^*(K_H) = x_j^*(K_H)$ and $x_i^*(K_L) = x_j^*(K_L)$ where $i \neq j$; it yields:

$$x_i^*(K_H) = \frac{\dfrac{1}{K_H} G\left(\dfrac{c_H}{K_H}\right) - (n-1)(1-\theta)\dfrac{K_L}{K_H} x_j^*(K_L)}{1+(n-1)\theta} \qquad (14)$$

and

$$x_i^*(K_L) = \frac{\dfrac{1}{K_L} G\left(\dfrac{c_L}{K_L}\right) - (n-1)\theta \dfrac{K_H}{K_L} x_j^*(K_H)}{1+(n-1)(1-\theta)} . \qquad (15)$$

Since a high type participant's work efficiency is higher than low type one's, i.e., $\frac{K_H}{c_H} > \frac{K_L}{c_L}$, persons with higher knowledge level always contribute their effort in this model. On the other hand, assuming that all low type participants don't work at all, i.e., $x_i^*(K_L) = 0$, the necessary and sufficient condition for a low type participant to free ride on the others is $G\left(\frac{c_L}{K_L}\right) \leq \frac{(n-1)\theta}{1+(n-1)\theta} G\left(\frac{c_H}{K_H}\right)$. This also implies that when information is rife that most of persons are low type participants, i.e., $\theta < G\left(\frac{c_L}{K_L}\right) \Big/ \left((n-1)\left(G\left(\frac{c_H}{K_H}\right) - G\left(\frac{c_L}{K_L}\right)\right)\right)$, low type participants prefer to contribute their effort rather than shrinking. $G\left(\frac{c_L}{K_L}\right) \Big/ \left((n-1)\left(G\left(\frac{c_H}{K_H}\right) - G\left(\frac{c_L}{K_L}\right)\right)\right)$ is denoted as $\hat{\theta}$ for conciseness. Each participant based her private type has two strategies relying on whether θ is less than $\hat{\theta}$ or not. Hence, given $\theta < \hat{\theta}$, solving (14) and (15) simultaneously yields $x_i^*(K_H)$ and $x_i^*(K_L)$. Given $\theta \geq \hat{\theta}$, plugging $x_i^*(K_L) = 0$ into (14) yields new $x_i^*(K_H)$. We list the results as follows:

$$x_i^*(K_H) = \begin{cases} \dfrac{1}{nK_H}\left(G\left(\dfrac{c_H}{K_H}\right) + (n-1)(1-\theta)\left(G\left(\dfrac{c_H}{K_H}\right) - G\left(\dfrac{c_L}{K_L}\right)\right)\right) & \text{if } \theta < \hat{\theta} \\ G\left(\dfrac{c_H}{K_H}\right)\left((1+(n-1)\theta)K_H\right)^{-1} . & \text{if } \theta \geq \hat{\theta} \end{cases} \qquad (16)$$

and

$$x_i^*(K_L) = \begin{cases} \dfrac{1}{nK_L}\left(G\left(\dfrac{c_L}{K_L}\right) - (n-1)\theta\left(G\left(\dfrac{c_H}{K_H}\right) - G\left(\dfrac{c_L}{K_L}\right)\right)\right) & \text{if } \theta < \hat{\theta} \\ 0 & \text{if } \theta \geq \hat{\theta} \end{cases} . \qquad (17)$$

Thus, the expected total effective level of effort under asymmetric information is

$$E[Q] = \sum_{i=0}^{n} \binom{n}{i} \theta^i (1-\theta)^{n-i} \left(i \cdot K_H x_i^*(K_H) + (n-i) \cdot K_L x_i^*(K_L)\right) = n\left(\theta K_H x_i^*(K_H) + (1-\theta) K_L x_i^*(K_L)\right)$$

which implies

$$E[Q] = \begin{cases} \dfrac{n\theta}{1+(n-1)\theta} G\left(\dfrac{c_H}{K_H}\right) & , \text{if } \theta \geq \hat{\theta} \\ \theta G\left(\dfrac{c_H}{K_H}\right) + (1-\theta) G\left(\dfrac{c_L}{K_L}\right) & , \text{if } \theta < \hat{\theta} \end{cases} . \qquad (18)$$

Although low type participants free ride on high type ones when $\theta \geq \hat{\theta}$, the expected total effective level of effort increases with θ. Low type participants prefer to shrink rather than exert effort when the expected total effective level of effort is greater than $\frac{n}{n-1} G\left(\frac{c_L}{K_L}\right)$.

Proposition 4 In the incomplete-information case (the knowledge type of each participant is private information),

(a) although high type participants are still pivotal contributors, the expected total effective level of effort under incomplete-information is less than that under complete- information unless θ approaches one,
(b) the more the number of attendants, the more the motivation for low type participants to free ride, and
(c) when the number of attendants is 'mild' and knowledge-cost ratio of high type participants is close to that of low type participants, participants of both types would exert the effort.

4. INCENTIVE-COMPATIBLE INCENTIVE MECHANISM (SCREENING, TRUTH REVELATION)

Since participants' types are unknown, in this section we consider whether there exists a payment mechanism, or a contract, such that each participant, based on maximizing individual benefit, truthfully reveals her type to achieve social optimum. This contract can be described as $[P_H, x_H]$ and $[P_L, x_L]$; that is, each participant feels free to pick one of the two options, and then achieves the stated workload and receives the deserved subsidy. Under this architecture, P_H and P_L is the subsidy paid to participants who report their ability for high type or low type, respectively.

Hence, under this mechanism we must have two incentive-rationality (*IR*) constraints; that is; no matter what contract each participant signs, she earns a nonnegative payoff after ending the activity. We denote these two constraints as (*IRH*) and (*IRL*) where '*H*' and '*L*' represent a participant's type. In order to let each participant all truthfully reveal her type, we must have another two incentive-compatibility (*IC*) constraints; that is; because each participant can't earn more payoff by mimicking the behavior of the other type, they sign contracts based on their individual type. These two constraints are denoted as (*ICH*) and (*ICL*). Thus, this framework can be described as

$$\max_{x_H, x_L} \quad W = nf\left(n\bar{K}\right) - n\bar{c}$$

subject to

$$f\left(K_H x_H + (n-1)\bar{K}\right) - c_H x_H + P_H \geq f\left(K_H x_L + (n-1)\bar{K}\right) - c_H x_L + P_L \qquad (ICH)$$

$$f\left(K_L x_L + (n-1)\bar{K}\right) - c_L x_L + P_L \geq f\left(K_L x_H + (n-1)\bar{K}\right) - c_L x_H + P_H \qquad (ICL)$$

$$f\left(K_H x_H + (n-1)\bar{K}\right) - c_H x_H + P_H \geq 0 \qquad (IRH)$$

$$f\left(K_L x_L + (n-1)\bar{K}\right) - c_L x_L + P_L \geq 0 \qquad (IRL)$$

where $\bar{K} = \theta K_H x_H + (1-\theta) K_L x_L$, and $\bar{c} = \theta c_H x_H + (1-\theta) c_L x_L$.

Our approach to this problem is to relax it by delete all constraints, solve the relaxed problem, and check whether there exists P_H and P_L to satisfy these omitted incentive constraints. The following proposition shows that there exists a payment mechanism based on the expected number of high type participants, i.e., $n\theta$, to maximize the program.

Proposition 5 Assume $\theta > 0$. Let the contracts be:

$$\left[P_H = c_H x_H^*, x_H^* = \frac{1}{n\theta K_H} G\left(\frac{c_H}{nK_H}\right)\right],$$

$$\left[P_L = f\left(K_H x_H^* + (n-1)\bar{K}\right) - f\left((n-1)\bar{K}\right), x_L^* = 0\right].$$

Then, all participants truthfully reveal their type and exert the assigned effort. (See Appendix A)

Thus, the expected total effective level of effort under screening is $E[Q] = G\left(\frac{c_H}{nK_H}\right)$, which is the same as the socially optimal total effective level of effort under complete information in a situation where there exists at least one high type participant in the group. The proposition 5 suggests two things: first, to make high type participants act as pivotal contributors, the function of P_H is to exempt high type participants from the cost of exerting effort. Because the cost of exerting effort to a low type participant is higher than that to high type one, a low type participant has no incentive to deviate from accepting P_H if P_L is 'large enough'. Second, to make low type participants truthfully report their ability, a fixed fee based on the number of attendants is necessary to entice low type participants to be honest. However, the price of P_L must be commonplace so as to prevent high type participants from envying low type ones, even if they not only free ride on the high type participants but also earn extra payments.

5. NUMERICAL EXAMPLE

We apply a specific form, $f(x) = x^{\alpha}$ (where $0 < \alpha < 1$), to examine the behavior of participants under asymmetric information without incentive mechanisms. Given $\alpha = \{0.45, 0.5, 0.55\}$, $n = 10$, $c_H = 5$, $K_H = 55$, $c_L = 5.5$, and $K_L = 50$, the expected total effective level of effort, $E[f(Q)]$, varies depending on θ and α as shown in

Figure 1

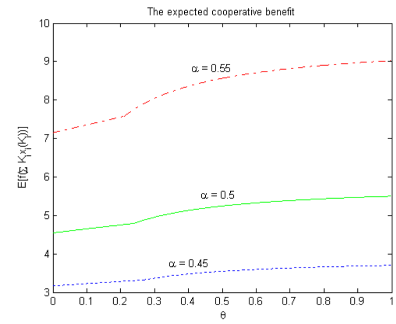

Figure 2

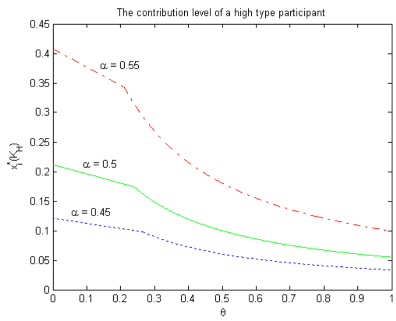

Figure 3

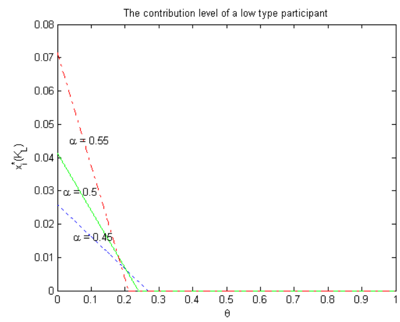

Figure 1. The contribution level of a high type participant and one of a low type participant are shown in Figure 2 and Figure 3, respectively.

First, these figures reveal that although the efforts of participants are decreasing with θ, the expected knowledge integration level still increases as θ. Second, when knowledge value is greater than production cost, the effort exerted by high and low type participants will increase as α, the degree of concavity (see figure 2 and figure 3).

Second, the cooperative benefit under complete-information is always greater than the expected one under incomplete-information. However, unlike the complete-information case, low type participants exert their effort when θ and n are sufficient small. All observations suggest that an incentive mechanism is an essential dimension to knowledge integration, especially in the society full of uncertain contingency.

6. CONCLUSION

Knowledge integration is one of the keys to e-business which has more competitive advantage than traditional organizations. However, under a situation without incentive, everyone treats this issue from her personal viewpoint, such that technology fails to operate well. Thus, if we develop a knowledge management system only based on software engineering and user acceptance perspectives, the benefit of establishing the application is hard to achieve an anticipative level. Because of the effect of free-riding, the real value of a research team can't be measured only by the group size. Hence, to maximize the benefit of human resources, our belief is to make the best possible use of men/women. That is, we allocate high ability persons to core departments, and free or lighten their cost. For low ability persons, we should support a smaller reward to compensate their behavior for telling the truth. This research can be further extended to a multiple stages game to analysis the long-time performance of knowledge integration.

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APPENDIX A. PROOF OF PROPOSITION 5

Given the unconstrained mathematical program, by first-order condition, the following inequalities must be satisfied:

$$nf'\left(n\overline{K}\right)nqK_H \le nqc_H \qquad (A1)$$

$$nf'\left(n\overline{K}\right)n\left(1-q\right)K_L \le n\left(1-q\right)c_L \qquad (A2)$$

Because of $\frac{K_H}{c_H} > \frac{K_L}{c_L}$, (*A1*) will bind at the optimum so as to $\overline{K} = \frac{1}{n}G\left(\frac{c_H}{nK_H}\right)$. Thus, $x_H^* = \frac{1}{nqK_H}G\left(\frac{c_H}{nK_H}\right)$ and $x_L^* = 0$ will satisfy $\overline{K} = \frac{1}{n}G\left(\frac{c_H}{nK_H}\right)$ if given $q > 0$. Furthermore, let $P_H = c_H x_H^*$, $P_L = f\left(K_H x_H^* + \left(n-1\right)\overline{K}\right) - f\left(\left(n-1\right)\overline{K}\right)$ and check all incentive constraints as follows:

$$f\left(K_H x_H^* + \left(n-1\right)\overline{K}\right) - c_H x_H^* + P_H = f\left(K_H x_H^* + \left(n-1\right)\overline{K}\right) \ge 0 \qquad \text{(IRH)}$$

$$f\left(K_L x_L^* + \left(n-1\right)\overline{K}\right) - c_L x_L^* + P_L = f\left(K_H x_H^* + \left(n-1\right)\overline{K}\right) \ge 0 \qquad \text{(IRL)}$$

$$f\left(K_H x_L^* + \left(n-1\right)\overline{K}\right) - c_H x_L^* + P_L = f\left(K_H x_H^* + \left(n-1\right)\overline{K}\right) = f\left(K_H x_H^* + \left(n-1\right)\overline{K}\right) - c_H x_H^* + P_H \qquad \text{(ICH)}$$

$$f\left(K_L x_H^* + \left(n-1\right)\overline{K}\right) - c_L x_H^* + P_H = f\left(K_L x_H^* + \left(n-1\right)\overline{K}\right) + x_H^*\left(c_H - c_L\right) \le f\left(K_L x_L^* + \left(n-1\right)\overline{K}\right) - c_L x_L^* + P_L \qquad \text{(ICL)}$$