Interfaces with Other Disciplines

Reward systems for intra-organizational knowledge sharing

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Abstract

Knowledge sharing is one of the most critical steps in knowledge management activities. To achieve effective knowledge sharing, it is important to encourage workers to share their knowledge for the best interests of the firm. However, successfully exerting this encouragement is very challenging. In this paper, we develop a formal model and analyze reward systems for intra-organizational knowledge sharing. Specifically, two common forms of reward systems are considered; individual-based reward which is based on the individual contribution of valuable knowledge, and group-based reward which is based on the contribution of the whole group through knowledge sharing to the firm performance. Through the analysis, we derive a simple optimal individual-based reward system which depends on the amount and the productivity of shared knowledge. The system balances the benefit from knowledge sharing of each worker with the costs related with it. Next, it is found that group-based reward is not only less efficient than individual-based reward, but it also subject to a potential productivity problem, in which workers with more productive knowledge do not participate in knowledge sharing. Finally, it is shown that several organizational factors can complement reward systems in increasing the performance of KM and can mitigate the productivity problem. Insights from our analysis could help managers to understand important considerations in rewarding knowledge sharing, and could provide them with guides to implement reward systems.

Keywords: Economics; Cost benefit analysis; Intra-organizational knowledge sharing; Knowledge management; Reward system design

1. Introduction

Knowledge sharing is considered a critical step for successful knowledge management (KM). To remain competitive in the marketplace, organizational knowledge and expertise must be shared (Gold et al., 2001; Zack, 1999). Therefore, knowledge sharing activities are an indispensable component in KM processes (e.g., Alavi and Leidner, 2001; Davenport and Prusak, 1998; Gold et al., 2001; Goodman and Darr, 1998). However, many researchers have argued that knowledge sharing is also a critical hurdle for KM (e.g., Hansen, 1999; O’Dell and Grayson, 1998; Szulanski, 1996), an issue that has also been widely raised by industry
practitioners (Alavi and Leidner, 1999; King et al., 2002). For example, King et al. (2002) report that, from a survey of 2073 KM practitioners and executives, the challenge of “how to motivate individuals to contribute their knowledge to a KM system” was cited as one of the top issues in KM.

In fact, there are inherent barriers to knowledge sharing. Under intensive internal competition for rewards, status, and promotions in today’s organizations (Menon and Pfeffer, 2003), employees normally regard their unique knowledge as power to secure their positions in the organization (Ba et al., 2001b; Huber, 1982; Zack, 1999). This tendency is intensified in the presence of downsizing and job insecurity. In addition, there are inherent costs in sharing knowledge; time and energy are required to share knowledge, and these are finite resources (Davenport and Prusak, 1998; Goodman and Darr, 1998; Szulanski, 1996).

To address this issue, it has been emphasized that knowledge sharing should be rewarded through an organization’s formal incentive system (Alavi and Leidner, 1999; Ba et al., 2001b; Davenport and Prusak, 1998; Gold et al., 2001). There is much empirical evidence to suggest that organizational reward influences the behavior and performance of an organization’s members (e.g., Huber, 1991; Maltz and Kohli, 2000). In fact, many firms reward employees for knowledge sharing. For example, in most management consulting firms, knowledge sharing activities are considered in performance reviews and help determine bonuses and promotions. At Bain and Company, a quarter of a partner’s annual compensation is based on how much help he or she has given other colleagues (Hansen et al., 1999). These practices are also prevalent in other industry sectors (Business Week, 2001).

While previous studies have indicated the importance of reward in KM, little is known about how to design a reward system for knowledge sharing. The purpose of this study is to develop a formal model, and to analyze reward systems for intra-organizational knowledge sharing based on the model. The analysis could help managers to understand important considerations in rewarding knowledge sharing, and could provide them with guides to design reward systems.

The remainder of this paper is organized as follows: Following the literature review in the subsequent section, Section 3 develops the model used in our analysis. In Sections 4 and 5, two common reward systems are examined. Section 6 analyzes the effects of various factors other than rewards on knowledge sharing. Finally, Section 7 concludes with discussion and suggestions for future research.

2. Theoretical background

A number of drivers of knowledge sharing have been identified. One such driver is organizational citizenship behavior, which is defined as “individual behavior that is discretionary, not directly or explicitly recognized by the formal reward system, and that in the aggregate promotes the effective functioning of the organization” (Organ, 1988, p. 4). If the value of organizational citizenship behavior is shared and reinforced throughout the organization, knowledge sharing is more likely to increase (Goodman and Darr, 1998). Next, when an organization is characterized by mutual trust and high-care relationships among workers, individuals will be less likely to keep knowledge private (Hansen, 1999; Nonaka and Takeuchi, 1995; O’Dell and Grayson, 1998; von Krogh, 1998). Also, strong beliefs of organizational ownership norm, which implies that an organization owns the labor of the employees and the resulting outcomes such as ideas, inventions, or know-how, can attenuate the incentive to hoard knowledge (Constant et al., 1994; Jarvenpaa and Staples, 2001). Other organizational factors that encourage knowledge sharing include procedural justice or fairness (Bartol and Srivastava, 2002; Bock et al., 2005), organization’s commitment to knowledge sharing (Skymrme, 2002), and communication climate such as the extent of horizontal and vertical information flow, openness, and reliability of information (Malhotra and Majchrzak, 2004; van den Hooff and de Ridder, 2004).

Besides the organizational factors, individual motivational drivers have been widely emphasized (e.g., Alavi and Leidner, 1999; Ba et al., 2001b; Davenport and Prusak, 1998; Gold et al., 2001; Goodman and Darr, 1998), which can be classified into intrinsic motivation and extrinsic motivation. Individuals are intrinsically motivated when they seek enjoyment, interest, satisfaction, or self-expression in the work itself (Amabile, 1993). Intrinsic motivation includes self-efficacy and altruism. For example, by sharing their knowledge, individuals can be satisfied with the confidence in their ability to contribute to the organization or to help others (Constant et al., 1994; Kankanahalli et al., 2005). On the other hand, “individuals are extrinsically motivated when they engage in the work in order to obtain some goal that is apart from the work itself” (Amabile, 1993,
Common extrinsic incentives include monetary rewards, recognition, and promotion. Two basic prerequisites for extrinsic incentive systems to be effective are that it should be possible for the organization to observe or record the target behavior and to assess its value (Bartol and Srivastava, 2002).

Recently, it has been theorized that effective motivational instruments are contingent on KM strategy (Bartol and Srivastava, 2002). Hansen et al. (1999) classify KM strategies into one of two categories: the codification strategy, in which knowledge is codified and stored in repositories that are easily accessed, or the personalization strategy, in which knowledge is closely tied to its creator and is shared mainly through person-to-person contacts. Bartol and Srivastava (2002) argue that extrinsic incentives such as monetary reward systems based on individual knowledge sharing behavior are best suited to the codification approach because two basic prerequisites, recording and measuring the knowledge shared by individuals, are met most easily under the approach. On the other hand, they argue that extrinsic incentives under the personalization approach may not be as effective as under the codification approach: Rewards based on knowledge sharing behavior could play a relatively limited role in enabling knowledge sharing in such situations as “knowledge sharing through formal interactions” (e.g., periodic team or department meetings) or “knowledge sharing through informal interactions.” Finally, intrinsic motivation is most appropriate for influencing “knowledge sharing within community of practice.” Recent empirical studies (Kankanhalli et al., 2005; Ko et al., 2005) show consistent results with the theoretical prediction by Bartol and Srivastava (2002).

Although extrinsic rewards may sometimes undermine intrinsic motivation, extrinsic rewards can also convey a signal affirming competence of the individual that drives intrinsic motivation (Bartol and Srivastava, 2002). In addition, intrinsic motivation is more difficult to change, with more uncertain outcome than relying on extrinsic motivation; these inherent shortcomings often call for extrinsic incentives (Osterloh and Frey, 2000). Given the widely accepted role of extrinsic incentives, an important question that follows is how to design the incentive system for effective knowledge sharing, for which little research effort has been made.

This study deals with this question. Based on the above arguments, formal organizational reward systems for knowledge sharing would be most effective under the codification strategy, which involves explicit knowledge contribution to repositories. Therefore, the specific context for this study is a firm that pursues the codification strategy for KM, and we define knowledge sharing as “the conversion of knowledge into accessible and applicable formats” (Grover and Davenport, 2001) in the knowledge management system (KMS).

Under the codification strategy, it would be possible for a firm to implement an organizational reward system based on individual knowledge sharing behavior, termed an individual-based reward (IBR) in this paper. We derived an optimal IBR, which could provide guides for firms to design reward systems.

In some cases, however, it would be costly to reward each knowledge worker on an individual basis by her contribution. Then, another type of common incentive system, group level incentive system, could be applied. Bartol and Srivastava (2002) suggest that firms can “encourage knowledge sharing through indirect rewards—that is, rewards which depend on factors other than knowledge sharing, but which are likely to require knowledge sharing for successful performance.” For example, when outcomes such as performance are rewarded at the group level, an individual who shares knowledge with others are likely to think that the knowledge she shares will improve the performance of others, which in turn increases the reward for her. Therefore, she is likely to have a higher motivation to share knowledge. In this way, a firm can base the reward on the performance of the whole group (organization). Under common group level incentive system, the total incentive payment is usually divided among individuals according to formulas that do not depend on individual contribution (Farrell and Scotchmer, 1988; Milgrom and Roberts, 1992). This type of reward is termed group-based reward (GBR) in this study.

We find that in general, GBR is inferior to IBR in terms of the firm’s net payoff from knowledge sharing. Furthermore, we show that workers with more productive knowledge may not share their knowledge under a GBR. Through the extension of the basic model, we find that this potential problem may be mitigated by establishing organizational ownership norm.

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1 Examples of reward systems in this category include profit sharing and gain sharing.

2 In addition, GBR could work as a possible reward scheme under the personalization approach to KM because it does not require measurement of individual knowledge contribution.
In a related study, Sundaresan and Zhang (2004) analyze the impact of information systems and rewards on knowledge transfer. Paying attention to the role of IT investment in lowering knowledge transfer costs, they show that an IT investment can complement rewards in facilitating knowledge transfer. However, while they assume that the knowledge needed to complete a task is one dimensional, we explicitly consider an important feature of knowledge: complementarity (Ba et al., 2001a). KM involves the integration of different bodies of knowledge such as socialization and combination in knowledge conversion modes (Nonaka and Takeuchi, 1995). In our model, each worker has a different kind of knowledge, and the complementarity among these kinds of knowledge affects the optimal reward system and the workers’ knowledge sharing behaviors.

Ryu et al. (2005) identify “learning-from-others” through knowledge transfer as one of the most important leaning processes, and investigate patterns of optimal investment in learning processes. In their model, a worker’s willingness to share her knowledge with others is exogenously given, with no consideration of the effects of the extrinsic reward. In our model, however, workers’ decisions on knowledge sharing are endogenized: Each worker decides how much knowledge to share, based on the reward system offered by the organization. In the following section, we develop a model for analysis.

3. Model

Consider a firm with \( n \) knowledge workers. Each of them is assumed to be a self-utility maximizer as in Ryu et al. (2005). While there is a wide range of other motives for human behavior including needs for achievement, responsibility, and recognition (Donaldson, 1990), the simplified model of individual motivation to maximize self-utility could provide fruitful insights and does not limit the possibility of theoretical integration with traditional management theories (Barney, 1990). The firm is assumed to desire to increase the net payoff through KM because organizational knowledge ultimately contributes to financial performance of the firm (Chang and Ahn, 2005; Chen and Edgington, 2005). Also each knowledge worker is assumed to have unique knowledge, and therefore there is only one possible provider for each knowledge component. Further, a worker may have knowledge possessed by others. However, because common knowledge is not the main target of knowledge sharing, and because the unique and valuable components of individuals’ knowledge stock are the main source of power in an organization, we focus on the unique knowledge of each worker.

3.1. The firm’s objective

To model individual private knowledge, we use the concept of the knowledge unit (Davenport et al., 1996; Zack, 1999), which is “a formally defined, atomic packet of knowledge content that can be labeled, indexed, stored, retrieved, and manipulated” (Zack, 1999, p. 48). Let us denote \( k = (k_1, \ldots, k_n) \), where \( k_i \) indicates the units of unique knowledge that knowledge worker \( i \) has. For example, in a consulting firm context, each consultant acquires knowledge from the projects that she participates in. So, the number of projects the consultant has completed can be a measure of the knowledge units possessed by that consultant.\(^3\)

Then, suppose a situation where private knowledge is shared and utilized by other workers. Denote \( s = (s_1, \ldots, s_n) \), where \( s_i \leq k_i \) represents the units of knowledge shared out of \( k_i \) by worker \( i \).\(^4\) In the following, \( k_i \) and \( s_i \) are treated as continuous variables for analytical simplicity as in Sundaresan and Zhang (2004). Compared with before knowledge sharing, a firm can generate an additional payoff because knowledge that was previously held private can now be utilized by others. Let \( F(s; k) \) denote the additional payoff given \( s \) and \( k \). The additional payoff from KM can be obtained by using the knowledge base to either increase the value or decrease the costs of the firm’s products or services (Chen and Edgington, 2005; Ofek and Sarvary, 2001).\(^5\)

Although there have been some concerns about the difficulty in identifying the contribution of KM to the firm performance, attempts have been made to measure the value of investments in KM (Chang and Ahn,

\(^3\) While all projects may not be successful, as Teece (1998) argues, knowledge of failures (“this approach does not work”) is also valuable.

\(^4\) At McKinsey and Company, for example, the number of a consultant’s publications is used as a measure of knowledge sharing and is an important factor in determining promotions (Alavi and Leidner, 1999).

\(^5\) The increased value of products or services enables the firm to charge higher prices or to sell more, generating more revenue.
knowledge sharing issue given private knowledge. However, we do not consider this alternative measure because we focus not on the knowledge creation issue but on the knowledge sharing issue given private knowledge.

Implementing KM is costly for the firm. For example, the firm should maintain KM staff, build a KMS, and provide rewards. The cost, $C_F$, can be of two types: one is independent of the reward system (e.g., costs to maintain KM staff and to build the knowledge repository and communications networks – Ofek and Sarvary, 2001), and the other is reward-specific. The former can be normalized to be zero for simplicity, and the firm’s net payoff from knowledge sharing ($\pi$) is represented by $F(s,k) - C_F(s,k)$. Then, the firm tries to maximize the net payoff through KM. The net payoff measures the net financial contribution of KM to the firm’s performance.

$F$ is assumed to be increasing and concave in $s_i$. This assumption has been adopted in the literature (e.g., Cohen and Levinthal, 1989; Samaddar and Kadiyala, 2006) and fits well with organizations in which performance is mainly characterized by incremental innovations rather than by radical ones. New product development, for example, is one of the most important knowledge creating endeavors (Madhavan and Grover, 1998; Nonaka and Takeuchi, 1995), but it is still dominated by incremental innovations. According to Cooper (2001), only 10% of new products are radical innovations that are “new to the world.” From the perspective of performance, Cooper’s study shows that products of low innovation are as profitable as highly innovative ones. Most knowledge service firms are also characterized by incremental innovations. For example, management consulting firms generate business solutions for their customers by drawing on their collective past and present experiences (Ofek and Sarvary, 2001). These firms identify, integrate, and transfer experience and solutions between clients, so the very nature of most business solutions suggested by them is incremental. Although return to knowledge may be characterized by S-shaped curve in some situation, this possibility is excluded in the analysis because of the analytical simplicity.

Next, we introduce two useful concepts in the analysis: First, each worker’s knowledge is usually different in terms of its potential contribution to the firm performance (Lin et al., 2005). To model this difference, the productivity of worker $i$’s knowledge is defined as $\partial F(s; k)/\partial s_i$, the marginal contribution of worker $i$’s shared knowledge to the payoff. This definition implies that as the productivity of worker $i$’s knowledge increases, so does the contribution of worker $i$’s shared knowledge to the payoff. The definition also incorporates the possibility that the productivity of worker $i$’s knowledge may depend on other workers’ knowledge sharing amounts ($s_j$).

Second, KM involves the integration of different bodies of knowledge each worker has (Nonaka and Takeuchi, 1995). Knowledge components are often interdependent and complementary with each other: for example, in a pharmaceutical company, knowledge of the effects of a certain chemical substance can be combined with knowledge of other substances to generate a new drug treatment (Ba et al., 2001a). We capture this example, in a pharmaceutical company, knowledge of the effects of a certain chemical substance can be combined with knowledge of other substances to generate a new drug treatment.

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6 Given $s$ and $k$, $F(s; k)$ may be stochastic rather than certain due to various factors such as market competition, and changes in customers’ needs and the economic environment. However, the results in this paper remain the same with the relaxed assumption that the firm knows the expected value of the additional payoff given $s$ and $k$, as in Samaddar and Kadiyala (2006).

7 In addition to the measurement of total value contribution of KM at the aggregate level, Bartol and Srivastava (2002) argue that it is possible for firms to measure the value of each knowledge contribution under the codification approach because knowledge contribution is recorded and firms usually have validation systems composed of knowledge experts. This explains why the consulting industry is often blamed for recycling old advice without providing innovative solutions (O’Shea and Madhavan, 1997).

9 The marginal contribution of worker $i$’s total private knowledge, $\partial F(s; k_i)$, can also be a measure of the productivity of worker $i$’s knowledge. However, we do not consider this alternative measure because we focus not on the knowledge creation issue but on the knowledge sharing issue given private knowledge.
dependence, $\frac{\partial^2 F(s,k)}{\partial s \partial s_t} = 0$. Therefore, higher knowledge interdependence implies a higher level of complementarity or synergy between knowledge components. Although negative interdependence may exist in some situations, we rule out this case for simplicity. For expositional simplicity, the parameter $k$ is omitted whenever possible.

3.2. Knowledge sharing costs incurred by workers

There are inherent barriers to knowledge sharing which impose costs on potential knowledge contributors. Our model includes two important types of such costs. First, employees normally regard their unique knowledge as power in the organization (Ba et al., 2001b). If other people gain the knowledge, the owners of the knowledge may lose power, which would threaten their positions in the organization (Ba et al., 2001b; Davenport and Prusak, 1998; Goodman and Darr, 1998; Huber, 1982; Szulanski, 1996). Therefore, workers get utility by keeping knowledge private. $P(k_i)$, utility of power, denotes the utility in monetary terms worker $i$ gets from private knowledge amount of $k_i$. Then, after sharing $s_i$ units of knowledge, worker $i$'s utility of power becomes $P(k_i - s_i)$. Thus, $P(k_i) - P(k_i - s_i)$ amounts to costs incurred by sharing $s_i$ units of knowledge. It is reasonably assumed that utility of power increases as the amount of unique knowledge increases, that is, $P'(k_i) > 0$. We further assume that $P'(k_i) < 0$, because a worker with a lot of unique knowledge would get less increase of utility of power from an additional unit of private knowledge, compared with a worker who has only a small amount of knowledge. This implies that the more knowledge a worker shares, the more rapidly the utility is decreased.

Another source of disutility is the time and effort to make knowledge explicit and to structure it so that it can be disseminated (Davenport and Prusak, 1998; Goodman and Darr, 1998). Let us denote $C(s_i)$ as worker $i$'s costs of time and effort in monetary terms incurred by sharing $s_i$ units of knowledge. Then, $C'(s_i) > 0$, that is, the more one shares, the more costs of time and effort are required. Since time is the firm’s resource most likely to be begrudged to knowledge activists (Davenport and Prusak, 1998), workers should contribute their knowledge at the cost of either time for their duties or off hours. Furthermore, under the codification approach, the costs of creating documents and indexing them for reuse escalate (Markus, 2001). Based on these arguments and previous literature (e.g., Barua et al., 1995; Kandel and Lazear, 1992; Lal and Srinivasan, 1993), $C$ is assumed to be convex in $s_i$ ($C''(s_i) > 0$) and of the same functional form for all workers.

To complete knowledge transfer, knowledge should not only be contributed by its owners but also should be absorbed and applied by the recipients. Markus (2001) identifies four distinct types of knowledge reuse situations involving different knowledge reusers; shared work producers, shared work practitioners, expertise-seeking novices, and secondary knowledge miners. Among the four situations, she argues that applying knowledge involves difficulty only for expertise-seeking novices because of the possible lack of ability to apply it successfully. Although this situation may be of concern in some cases, we limit our attention to the costs from the perspective of knowledge owners because contributing knowledge is the first step toward leveraging knowledge assets in an organization (Kankanhalli et al., 2005).

Now, suppose the following situation. First, the firm announces a reward system on knowledge sharing. Then, each worker decides to share a certain amount of knowledge, $s_i(>0)$, or decides not to participate in knowledge sharing. In the latter case, the worker’s utility does not change. Finally, the firm rewards participating workers based on the reward system. In the following sections, we analyzed reward systems based on the model.

4. Analysis of individual-based reward system

Under the codification strategy, individual knowledge contribution can be easily recorded and measured (Bartol and Srivastava, 2002). In this section, we analyze the IBR system, in which reward for each knowledge worker is determined by her contribution to the knowledge repository. First, an incentive compatible reward system is derived. Then, we investigate the effects of knowledge amount and productivity on knowledge sharing.

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10 The results in this paper, however, remain the same under negative interdependence.
4.1. Incentive compatible reward system

Denote $R_i$ as the reward for worker $i$. It is the worker’s problem to decide the optimal level of knowledge sharing to maximize her total utility, given the reward system. After sharing $s_i$ units of knowledge, and thereby incurring the costs of $C(s_i)$, worker $i$ has power of $P(k_i - s_i)$ and receives reward $R_i(s_i)$. Therefore, worker $i$’s problem (P1) and the corresponding first-order condition (FOC) are as follows:

$$\max_{s_i} z_{p1} = P(k_i - s_i) - C(s_i) + R_i$$  \hspace{1cm} (1)

and

$$\frac{\partial P(k_i - s_i)}{\partial s_i} - C'(s_i) + \frac{\partial R_i}{\partial s_i} = 0.$$  \hspace{1cm} (2)

Worker $i$ chooses knowledge sharing amount satisfying Eq. (2). $-\frac{\partial P(k_i - s_i)}{\partial s_i}$ and $C'(s_i)$ are marginal loss of power and marginal cost of time and effort to increase the knowledge sharing amount, respectively. Thus, Eq. (2) implies that in choosing the optimal $s_i$, the worker considers the balance between marginal increase of costs (loss of power and cost of time and effort) and marginal increase of reward, $\frac{\partial R_i(s_i)}{\partial s_i}$, associated with knowledge sharing.

The firm’s problem (P2) is determining both the optimal level of knowledge sharing and the corresponding reward scheme for each worker, in an effort to maximize the net payoff, considering the workers’ incentive to maximize their own utility as shown in (2).

$$\max_{s_1, \ldots, s_n} \pi_{p2} = F(s) - \sum_{i=1}^{n} R_i$$  \hspace{1cm} (3)

s.t.  \hspace{1cm} $P(k_i - s_i) - C(s_i) + R_i \geq P(k_i), \quad \forall i,$  \hspace{1cm} (4)

$$\frac{\partial P(k_i - s_i)}{\partial s_i} - C'(s_i) + \frac{\partial R_i}{\partial s_i} = 0, \quad \forall i.$$  \hspace{1cm} (5)

The participation constraints in (4) imply that, to encourage the worker to participate in knowledge sharing, the firm should provide a reward level which guarantees that the worker’s utility will not decrease after sharing knowledge. The incentive compatibility constraints in (5) are the workers’ FOC’s in (2); they imply that the firm should consider that the workers will react to the reward system by choosing the knowledge sharing amount which is optimal for them. To derive an optimal reward system, the following lemma is used; the proof is shown in Appendix A.

**Lemma 1.** *The constraints (4) in (P2) are binding at the optimum.*

In other words, Lemma 1 says that at the optimum, the worker’s utility after knowledge sharing will be the same as the utility before knowledge sharing. Therefore, after substituting the equality participation constraints for $R_i(s_i)$ in (3), the firm’s FOC is obtained as follows:

$$\frac{\partial F(s)}{\partial s_i} + \frac{\partial P(k_i - s_i)}{\partial s_i} - C'(s_i) = 0, \quad \forall i.$$  \hspace{1cm} (6)

Eq. (6) implies that the firm should balance the benefit and costs to the firm of increasing knowledge sharing amount. $\frac{\partial F(s)}{\partial s_i}$ represents the benefit since it is the marginal increase of the payoff. On the other hand, $-\frac{\partial P(k_i - s_i)}{\partial s_i} + C'(s_i)$ represents the cost since it is the sum of marginal loss of power and marginal cost of time and effort, which should be compensated to increase knowledge sharing amount. Therefore, the optimal $s_i$ is the amount at which the marginal benefit of increasing knowledge sharing amount is the same as the marginal cost associated with it.

The second-order conditions are satisfied since the partial derivative of the left-hand side of (6) with respect to $s_i$ is negative. With $F$ convex in $s_i$, the analysis leads to the same results as long as the corresponding second-order condition is satisfied, or the convexity of $F$ is moderate. Therefore, our analysis is valid as long as the
organization is not very radically innovative, or knowledge in the organization does not generate very sharply increasing returns.

Denote \( s^* = (s_1^*, \ldots, s_n^*) \) as the solution to the firm’s FOCs. By comparing (5) and (6), an incentive-compatible reward system can be obtained as follows, where \( b_i \) is derived using Lemma 1.

**Proposition 1.** The following linear IBR system is incentive compatible:

\[
R_i(s_i) = a_is_i + b_i = \frac{\partial F(s^*)}{\partial s_i} s_i + P(k_i) - P(k_i - s_i^*) + C(s_i^*) - \frac{\partial F(s^*)}{\partial s_i} s_i^*
\]

(7)

Therefore, the simple reward system (7), which is linear in knowledge sharing amount of each worker, provides an incentive compatible solution. Note that no restrictions were imposed on the functional form of \( R_i \) and \( R_i(s_i) \) is used in (7) instead of \( R_i \) because the above reward system is a function of \( s_i \). In the following, \( a_i \) and \( b_i \) are termed the marginal reward and base reward, respectively. The reward system in (7) is individual-based because the reward equation is different for each worker.

In addition, the reward system takes into account both the amount \( (s_i) \) and the productivity \( (\partial F(s)/\partial s_i) \) of shared knowledge. The marginal reward is the productivity of shared knowledge at the optimum. To understand how changes in the productivity affect the optimal amount of knowledge sharing and reward systems, suppose the productivity of worker \( i \)'s knowledge is increased while that of others remain unchanged under positive knowledge interdependence. Then, the left-hand side of Eq. (6) becomes positive at \( s_i^* \), the optimum before the increase of the productivity. Therefore, \( s_i \) should be increased to satisfy (6). Because this increase of \( s_i \) in turn, increases the left-hand side of the FOC for \( j \neq i \) in (6), \( s_j \) should also be increased from \( s_j^* \) to satisfy (6). Thus, the increase of the productivity of worker \( i \)'s knowledge increases the optimal knowledge sharing amount of worker \( i \), and increases that of other workers under positive interdependence. In this case, because \( \partial P(k_i - s_i)/\partial s_i - C'(s_i) \) in (6) decreases in \( s_i \), \( \partial F(s)/\partial s_i \) at the optimal \( s_i \) should be increased. Therefore, the marginal reward for worker \( i \) \( (a_i) \) should also be increased. Similarly, the marginal rewards for other workers should also be increased.

With the reward system given in (7), each worker shares \( s_i^* \). Then, the reward for worker \( i \) and the net payoff of the firm are, respectively, as follows:

\[
R_i(s_i^*) = P(k_i) - P(k_i - s_i^*) + C(s_i^*)
\]

(8)

and

\[
\pi_{p2} = F(s^*) - \sum_{i=1}^n \{ P(k_i) - P(k_i - s_i^*) + C(s_i^*) \}
\]

(9)

Eq. (8) shows that under the reward system in (7), the reward received by the worker exactly equals her loss of utility of power plus the cost of time and effort. That is, the worker gets zero surplus if she shares \( s_i^* \), and negative surplus otherwise. Therefore, the firm takes the entire surplus except the costs of knowledge sharing incurred by each worker, \( R_i(s_i^*) \).

4.2. The effects of knowledge amount and productivity on knowledge sharing

Here, we examine the effect of knowledge amount \( (k_i) \) and the productivity of knowledge on the optimal knowledge sharing \( (s_i^*) \). Lemma 2 summarizes the results; the proof is provided in Appendix A.

**Lemma 2.** The optimal knowledge sharing \( s_i^* \) is characterized as follows:

<table>
<thead>
<tr>
<th>Amount of knowledge</th>
<th>Interdependence</th>
<th>Productivity of knowledge (PK)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PK(_i) &gt; PK(_j)</td>
<td>PK(_i) = PK(_j)</td>
</tr>
<tr>
<td>( k_i = k_j )</td>
<td>Zero or positive</td>
<td>( s_i^* &gt; s_j^* )</td>
</tr>
<tr>
<td>( k_i &gt; k_j )</td>
<td>Zero</td>
<td>( s_i^* &gt; s_j^* )</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>Mostly, ( s_i^* &gt; s_j^* )</td>
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</tbody>
</table>
From the first row in the above table, when workers are homogeneous in terms of the amount of their knowledge \((k_i = k_j\) for all \(i \neq j\), the optimal knowledge sharing amount is larger for a worker with more productive knowledge than a worker with less productive knowledge, regardless of the interdependence. To investigate how a firm should design reward systems for workers with different levels of productivity of knowledge, consider the case in which worker \(i\) has more productive knowledge than worker \(j\) \((PK_i > PK_j)\). Then, \(s_i^* > s_j^*\). Since the sign of the second and the last parentheses in (A.1) in Appendix A is negative and positive, respectively, the first parentheses should be positive to satisfy (A.1). Therefore, \(a_i = \partial F(s^*)/\partial s_i > a_j(=\partial F(s^*)/\partial s_j).\)

Next, suppose that \(b_i \geq b_j\). Then, \(R_i(s_i) = a_i s_i + b_i > R_j(s_j) = a_j s_j + b_j\) for all \(s_i\). Since \(R_i(s_i^*) = a_i s_i^* + b_i > R_j(s_j^*) = P(k) - P(k - s_j^*) + C_w(s_j^*)\), worker \(i\) gets positive net utility by sharing \(s_i^*\). This leads to a contradiction to the result in Section 3.1 that workers should get zero net utility. Thus, \(b_i < b_j\). Therefore, other things being equal, a firm should set a higher marginal reward and a lower base reward for a worker with more productive knowledge.

Next, consider the case where worker \(i\) has more knowledge than worker \(j\) \((k_i > k_j)\) (the second row in the above table). Then, worker \(i\) incurs a lower cost of sharing a given amount of knowledge than worker \(j\), and therefore a lower marginal cost of sharing. When \(PK_i \geq PK_j\) under zero interdependence, the firm’s benefit from worker \(i\)’s knowledge is equal to or higher than that from worker \(j\)’s. Therefore, in this case, the firm should induce more knowledge sharing from worker \(i\) to balance the benefit and cost of knowledge sharing in Eq. (6), that is, \(s_i^* > s_j^*\). In the other cases in Lemma 2, however, the relative amount of the optimal knowledge sharing is not uniquely determined although \(s_i^* > s_j^*\) in most cases.

Lemma 2 shows that, in general, a worker with more amount of knowledge or more productive knowledge should be induced to share more because a worker with more knowledge loses less utility in sharing knowledge and because more productive knowledge contributes more to the firm performance.

Fig. 1 illustrates optimal knowledge sharing amount under conditions of varying productivity of knowledge, knowledge amount, and knowledge interdependence for specific functional forms with \(n = 3\). The functional forms are given in Appendix B, and the parameter values are given in the figure. Case I is the base case, where all of the three workers have the same amount of knowledge of 10 and the productivity of knowledge is the same for workers 1 and 2. The productivity of worker \(i\)’s knowledge is captured by the parameter \(a_i\). As the productivity of worker \(3\)’s knowledge \((a_3)\) increases, so does the worker’s optimal knowledge sharing amount (I-2). From the curves I-1 and I-2, the optimal knowledge sharing of worker \(3\) is lower than that of worker \(1\) (or worker \(2\)) for \(a_3 < 0.2(=a_1 = a_2)\), and higher for \(a_3 > 0.2\). Note that the optimal knowledge sharing of worker \(1\) also increases with \(a_3\) because of the positive interdependence \((\beta_{ij} = 0.1\) for all \(i \neq j\)).

In case II, knowledge interdependence is stronger \((\beta_{ij} = 0.2)\) than in case I. By comparing I-1 with II-1 and I-2 with II-2, respectively, we can find that knowledge sharing increases with the increase of knowledge interdependence. In case III, the amount of worker \(3\)’s knowledge is increased compared to case I. This increases
not only the optimal knowledge sharing of worker 1 but also that of the other workers due to the positive interdependence (compare I-1 with III-1 and I-2 with III-2, respectively). Note, from the curves III-1 and III-2, that while the optimal knowledge sharing is usually higher for a worker with more knowledge (worker 3), a worker with less knowledge (worker 1 or 2) should share more when the productivity of her knowledge is sufficiently higher.

5. Analysis of group-based reward system

In the previous section, we derived an optimal IBR, which could provide design principles for reward systems under the codification strategy. However, it would often be costly to reward each knowledge worker on an individual basis by her contribution as in IBR. Then, a firm can base the reward on the performance of the whole group \( F \) using a GBR. GBR is usually simpler and less costly to implement than IBR, because only one reward equation is needed for all the workers instead of \( n \) reward equations as in IBR, and because the firm have only to measure \( F \) to determine the reward amount instead of measuring all \( s_i \) for each worker. In addition, GBR can be a practical means to reward knowledge sharing under the personalization strategy because individual contribution is inherently unobservable under the strategy.

Suppose a GBR system in the simplest form, \( R_i = cF(s_i) + d \), in which each worker receives an equal portion of the total payoff. Then, the worker’s problem (P3) is

\[
\max_{s_i} \quad Z_{P3} = P(k_i - s_i) - C(s_i) + cF(s_i) + d. \tag{10}
\]

The firm’s problem (P4) is as follows:

\[
\max_{s_1, \ldots, s_n} \quad \pi_{P4} = F(s) - \sum_{i=1}^n (cF(s_i) + d) \tag{11}
\]

s.t. \[
P(k_i - s_i) - C(s_i) + cF(s_i) + d \geq P(k_i), \quad \forall i, \tag{12}
\]

\[
\frac{\partial P(k_i - s_i)}{\partial s_i} - C'(s_i) + c \frac{\partial F(s_i)}{\partial s_i} = 0, \quad \forall i. \tag{13}
\]

The participation constraints in (12) are equivalent to

\[
R_i = cF(s_i) + d = \max_i \{ P(k_i) - P(k_i - s_i) + C(s_i) \}. \tag{14}
\]

Therefore, when workers are heterogeneous in terms of the productivity of knowledge or the amount of knowledge, some workers usually get positive net utility from knowledge sharing under the GBR. Although the optimal GBR cannot be derived explicitly, it can be shown that the GBR is always inferior to the IBR given in (7). That is, the firm’s net payoff is lower under the GBR than under the IBR. The main reason for this is that, contrary to the GBR, the IBR can individualize the reward rule based on the productivity and the amount of knowledge contributed by each worker.

Next, we examine the effects of knowledge amount \( (k_i) \) and the productivity of knowledge on the optimal knowledge sharing \( (s_i^*) \). Lemma 3 summarizes the results; the proof is shown in Appendix A.

**Lemma 3.** The results in Lemma 2 hold under the GBR system.

Lemma 3 shows that the effects of knowledge amount and the productivity of knowledge are unchanged under the GBR. Therefore, in general, a worker with more amount of knowledge or more productive knowledge is likely to share more.

Under the GBR, a firm may improve the net payoff by reducing the reward, thereby causing some workers with binding participation constraints to not participate in knowledge sharing under the reduced reward.

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**Notes:**

11. Simple linear reward equations have been frequently considered in the compensation literature (e.g., Barua et al., 1995; Kandel and Lazear, 1992).

12. However, when all workers are homogeneous in terms of the productivity of knowledge and \( k_i = k \) for all \( i \), we can derive an optimal reward system, under which the amount of knowledge sharing and the firm’s net payoff are the same as under the IBR in (7).
Suppose that all workers have the same level of productivity of knowledge, except for worker $n$, who has a higher level. If other things being equal, by Lemma 3, $s_1^* = \cdots = s^n_{n-1} < s^n_n$. Therefore, worker $n$ has a higher minimum reward requirement \( P(k_n) - P(k_n - s^n_n) + C(s^n_n) \) than the other workers do because she incurs a greater loss of power and a higher cost of time and effort. Since participation constraints are binding only for worker $n$, worker 1 through worker $n-1$ get positive net utility from knowledge sharing.

If the firm decreases the base reward $d$, worker $n$ does not participate in knowledge sharing since he gets negative net utility gain from sharing. Therefore, $F$ is reduced, which has a negative effect on the firm’s net payoff. On the other hand, a firm can decrease $d$ as long as the participation constraints are satisfied for worker 1 through worker $n-1$. This change would increase the net payoff without influencing the other $n-1$ workers’ optimal choices under $s_n = 0$. Therefore, it is better for a firm to decrease the base reward as long as the gain (reduced reward) from the decrease of the base reward is larger than the loss (reduced payoff). A firm can further increase the net payoff by changing both $c$ and $d$ to the optimal level under $s_n = 0$.

**Proposition 2** generalizes the argument.

**Proposition 2.** Under GBR, other things being equal, workers with more productive knowledge gain less (possibly zero) net utility from knowledge sharing than workers with less productive knowledge. In this case, a firm may reduce the reward to increase the net payoff, which induces the workers with more productive knowledge to not share their knowledge.

Fig. 2 shows a numerical example to illustrate Proposition 2 for $n = 4$. The functional forms are given in Appendix B, and the parameter values are given in the figure. All the workers have the same amount of knowledge of 10. While the productivity of knowledge is the same for workers 1–3, worker 4 has more productive knowledge. The productivity of worker $i$’s knowledge is captured by the parameter $x_i$. Then, the participation constraints are binding only for worker 4. The figure shows the net payoff when the firm induces all workers to share knowledge ($\pi^{**}$) and the net payoff when the firm reduces the reward causing worker 4 to not share her knowledge ($\pi'$). As the productivity of worker 4’s knowledge ($x_4$) increases, $\pi^{**}$ decreases because of the increase of the reward necessary to make worker 4 share knowledge. Note that the difference of the minimum reward requirement between worker 4 and the other workers increases with the difference of the productivity between them (the dotted line). In this case, workers 1–3 get positive net utility. $\pi^{**}$ eventually decreases to a level lower than $\pi'$ (for $x_4 > 0.073$). Therefore, the firm becomes better off by reducing reward, thereby causing worker 4 to not share.

The possibilities for a firm to reduce the reward increase as the variation of minimum reward requirements across the workers increases. In general, the productivity problem is more likely to occur as the heterogeneity of workers in terms of the productivity of knowledge increases. The above result represents a paradox in KM. Although firms adopt KM in order to secure valuable knowledge, GBR tend to produce a knowledge base lacking high quality, productive knowledge. Because GBR is awarded without considering the individual

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**Fig. 2. The firm’s incentive to reduce reward.**

- Parameter values: $k_i = k = k_i = 10$, $x_i = x = 0.05$.
- $\bar{a} = 0.02$, $\bar{y} = 2$, $v_i = v_i = v_i = u = 15$
- MRR: Minimum reward requirement for $f(MRR_1 + MRR_2)$
contributions of each worker, workers with productive knowledge may not be compensated sufficiently. In this case, there is an incentive for the workers to not contribute their knowledge to the firm’s knowledge base. In the following model extension section, the role of corporate norms regarding knowledge sharing is analyzed as an instrument to mitigate this problem.

6. Model extensions

In this section, the model and the analyses are extended in several ways to include other factors that have been emphasized as drivers of knowledge sharing. The effects of those factors on knowledge sharing and on the firm’s net payoff are investigated. Additionally, it is shown that the potential productivity problem under the GBR can be alleviated through organizational ownership norm.

6.1. Job security, trust, care, and organizational citizenship behavior (OCB)

When job security is low due to frequent layoffs or economic downturns, workers have a strong incentive to keep their unique power in the firm (Davenport and Prusak, 1998). Therefore, workers attach more utility to their private knowledge. Denote \( k > 0 \) as a job security parameter. The effect of job security can be analyzed by replacing power \( P \) by \( P/k \), where higher \( k \) implies higher job security.

On the other hand, when the level of trust or care between employees, or OCB, is high in a firm, workers feel the psychological cost of time and effort needed for sharing less because they are more concerned with how they can be useful to others and contribute to solving organizational problems (Constant et al., 1996). To capture the effect of those factors, \( C \) is replaced by \( C/l \), where \( l > 0 \). A higher value of \( l \) implies a higher level of trust, care, or OCB. 13

Then, for (P2) under IBR, \( P \) and \( C \) are replaced by \( P/k \) and \( C/l \), respectively. After substituting the binding participation constraints, the firm’s FOC becomes

\[
\frac{\partial F(s)}{\partial s_i} + \frac{1}{\lambda} \frac{\partial P(k_i - s_i)}{\partial s_i} - \frac{1}{\mu} C'(s_i) = 0. \tag{15}
\]

Denote \( s_i^+ \) and \( s_i^- \) as the optimal knowledge sharing under \( \lambda_1 \) and \( \lambda_2(> \lambda_1) \), respectively. As \( \lambda \) increases from \( \lambda_1 \) to \( \lambda_2 \), the left side of (15) becomes positive under \( s_i^+ \). Because each worker should increase knowledge sharing to satisfy the FOC, \( \partial s_i^+ / \partial \lambda > 0 \). Similarly, \( \partial s_i^- / \partial \mu > 0 \). These results show that a higher level of job security, trust, care, or OCB leads to increased knowledge sharing, which is consistent with the previous literature (e.g., Hansen, 1999; Jarvenpaa and Staples, 2001; von Krogh, 1998). However, interestingly, it can be shown that a higher \( \lambda \) or a higher \( \mu \) does not always increase knowledge sharing under GBR. This is because an increase of \( \lambda \) or \( \mu \), in general, changes the optimal marginal reward \( c \), under which \( s_i^+ \) does not necessarily increase. Therefore, contrary to the common assertion in the previous literature, the effect of those factors on knowledge sharing is contingent on the type of reward system used.

Next, what is the effect of those factors on the firm’s net payoff? It is found that the firm is always better off with increased job security, trust, care, or OCB (the proof is given in Appendix A). Finally, the inclusion of the parameters, \( \lambda \) and \( \mu \), does not affect any of the results in the previous sections. Proposition 3 summarizes the results.

**Proposition 3.** With a higher level of job security, trust, care, or OCB: (i) The firm’s net payoff always increases. (ii) Knowledge sharing increases under the IBR, but not always under the GBR. (iii) The results in the previous sections remain the same.

6.2. Organizational ownership norm (OON)

When OON is prevalent, workers feel that knowledge, even if a result of their hard work, must be used for the benefit of the organization as a whole (Jarvenpaa and Staples, 2001). Because the norm works as a

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13 While OCB refers to observable behaviors, trust and care are attitudes difficult to observe. However, their effects on the workers’ utility are similar in nature.
guideline to accepted and expected behavior (Bettenhausen and Murnighan, 1991), employees get more utility by sharing more knowledge in the presence of strong OON. By contrast, when they share less than others, they get negative utility because they fail to conform to the standards of behavior, and therefore they are derogated by others (Menon and Pfeffer, 2003). Therefore, the worker's problem under IBR (P5) can be modeled as follows, where $\tilde{\xi}(>0)$ denotes the intensity of OON, and $\bar{s} = (1/n) \sum s_i$:\footnote{The modeling approach is similar to Kandel and Lazear (1992) and Miyazaki (1984).}

$$\max_{s_i} Z_{P5} = P(k_i - s_i) - C(s_i) + R_i + \tilde{\xi}(s_i - \bar{s}).$$

(16)

Then, the firm's problem (P6) becomes

$$\max_{s_1, \ldots, s_n} \pi_{P6} = F(s) - \sum_{i=1}^{n} R_i$$

(17)

subject to

$$P(k_i - s_i) - C(s_i) + R_i + \tilde{\xi}(s_i - \bar{s}) \geq P(k_i) - \tilde{\xi} \sum_{j \neq i} \frac{s_j}{n}, \quad \forall i,$$

$$\frac{\partial P(k_i - s_i)}{\partial s_i} - C'(s_i) + \frac{\partial R_i}{\partial s_i} + \tilde{\xi} \frac{n-1}{n} = 0, \quad \forall i.$$ 

(18)

(19)

Note from the participation constraint in (18) that the utility that worker $i$ gets when she does not participate in knowledge sharing is $P(k_i) - \tilde{\xi} \sum_{j \neq i} s_j/n$ because of OON. The firm's FOC after substituting the binding participation constraints for $R_i$ in (17) is

$$\frac{\partial F(s)}{\partial s_i} + \frac{\partial P(k_i - s_i)}{\partial s_i} - C'(s_i) + \tilde{\xi} \frac{n-1}{n} = 0.$$ 

(20)

From (20), it is easy to see that as $\tilde{\xi}$ increases, so does $s_i^*$. Therefore, OON reinforces knowledge sharing under the IBR. Additionally, (20) shows that this effect is intensified as $n$ increases. Therefore, as the size of a firm increases, building OON can be a more effective way to induce knowledge sharing. However, similar to the effect of $\lambda$ or $\mu$, a higher $\tilde{\xi}$ does not always increase knowledge sharing under GBR.

Then, what is the effect of $\tilde{\xi}$ on the net payoff? It can be shown that a higher level of OON increases the net payoff. The proof is given in Appendix A.

Next, we show that the productivity problem under GBR can be mitigated because a positive $\tilde{\xi}$ reduces a firm's incentive to decrease the reward. Other things being equal, the participation constraint for a worker with the most productive knowledge is binding while workers with less productive knowledge gain positive net utility (see Proposition 2).\footnote{Note that Eq. (A.6) in the proof of lemma 3 does not change with the inclusion of $\tilde{\xi}$.} By rearranging the participation constraints, we have the following inequality for worker $i$, where the right-hand side is the minimum reward requirement for worker $i$:

$$cF(s) + d \geq P(k_i) - P(k_i - s_i) + C(s_i) - \tilde{\xi} \frac{n-1}{n} s_i.$$ 

(21)

From (21), a positive $\tilde{\xi}$ has an effect to decrease the minimum reward requirement through the term, $\tilde{\xi} (n-1) s_i/n$. The effect is larger for workers with more productive knowledge, who share more. Therefore, as $\tilde{\xi}$ increases, the variation of the minimum reward requirement across workers is usually reduced, which in turn reduces the firm’s incentive to decrease the reward to improve the net payoff. As a result, there is less possibility for workers with more productive knowledge to not participate in knowledge sharing. Therefore, by establishing a corporate norm that encourages knowledge sharing, a firm adopting GBR can expect the productivity problem to be alleviated.

Finally, the inclusion of $\tilde{\xi}$ does not affect any of the results in the previous sections except Proposition 2. The following proposition summarizes the results.

**Proposition 4.** With a higher level of OON: (i) The firm’s net payoff always increases. (ii) Knowledge sharing increases under the IBR, but not always under the GBR, and the effect of OON is intensified as $n$ increases. (iii) A
firm has less incentive to reduce the reward under the GBR, which mitigates the productivity problem. (iv) Excepting Proposition 2, the results in the previous sections remain the same.

7. Conclusion

Research on KM has been mainly qualitative or empirical work. Recently, attempts have been made to apply analytic approaches based on economic models (Chen and Edgington, 2005; Lin et al., 2005; Ryu et al., 2005; Samaddar and Kadiyala, 2006; Sundaresan and Zhang, 2004). Our study adds to this stream of literature by analyzing a crucial, but rarely addressed issue, how to design reward systems for intra-organizational knowledge sharing. The analysis in this study is based on a simplified model of knowledge sharing situation. However, the model captures important characteristics of such situation including the potential contribution of shared knowledge to the firm performance, workers' utility from their unique knowledge, time and effort for knowledge sharing, productivity and complementarity of knowledge components. The approach in this paper could provide a foundation on which further analyses of knowledge sharing and reward systems can be built.

The results in this paper should primarily be interpreted in terms of what factors managers should keep in mind in designing reward systems for knowledge sharing and how the factors interact with each other. We derive the following managerial implications from the results. First, in designing reward systems for knowledge sharing, managers should consider their organizational strategies for KM. Under the codification strategy, individual knowledge is stored explicitly in the repository. Therefore, individual contribution can be measured, and reward can be individualized (IBR) based on the contribution. However, when the organization adopts the personalization strategy for KM and therefore measurement of individual contribution is difficult, reward systems based on the performance of the whole group (GBR) instead of individual contribution could be a practical alternative.

Second, under the codification approach, a firm can efficiently capitalize on the knowledge asset by implementing a simple linear reward system. The reward system should be based on both the amount and the productivity of shared knowledge. The incorporation of the productivity implies that the firm should be careful in evaluating the potential contribution of the workers' knowledge to the firm performance. Another related implication is that it is not necessarily desirable to encourage workers to share as much knowledge as possible. Instead, in designing the reward system, the firm should consider the balance between the benefit and costs of increasing knowledge sharing amount of its workers. This is because excessive knowledge sharing incurs much cost from the workers' point of view while it does not contribute to the firm performance significantly.

Third, managers should keep in mind that GBR is not only less efficient than IBR, but also subject to the potential productivity problem. Under GBR, a firm may improve the net payoff by reducing the reward. In this case, workers with more productive knowledge may choose not to participate in knowledge sharing because it leads to negative net utility. Therefore, the resulting knowledge base tends to lack productive knowledge.

Fourth, the results from the model extension imply that reward systems and other organizational factors can complement each other. For example, the presence of job security, trust, care, and OCB could increase the firm performance by reducing the utility of power from unique knowledge or the cost of knowledge sharing. OON can also mitigate the productivity problem under GBR by reducing the variation of the workers' reward requirements. Therefore, managers should carefully keep an appropriate balance of the reward system and the organizational factors.

Although our study provides crucial implications, there are also areas that warrant further study. First, due to the static approach, our model could not include some important factors that are inter-temporal in nature. For example, reciprocity in knowledge sharing was not considered in our model. However, in reality, a knowledge worker may be willing to spend his time and effort to share knowledge if he expects those who would be benefited from his knowledge to share their knowledge in return (Constant et al., 1996; Davenport and Prusak, 1998).

Second, our model assumed that the potential contribution of shared knowledge to the payoff can be identified. Although attempts have been made to measure the functional relationship (e.g., Chang and Ahn, 2005)

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16 In Lee and Ahn (2005), the authors extend the analysis to a situation where there exists measurement inaccuracy in the actual amount of knowledge shared by risk-averse workers.
and the information about the value of explicit knowledge may disseminate easily (Lin et al., 2005), the estimation of the value of knowledge is still subject to uncertainty in many cases. Lin et al. (2005) address this issue from the perspective of information structure in knowledge transfer: information incompleteness and information asymmetry about the value of knowledge between a knowledge sender and knowledge receiver. They show that information incompleteness and asymmetry may interfere with knowledge transfer and suggest possible solutions such as signaling mechanism, based on a simple model of dyadic level focusing on the joint behavior of a sender and a receiver. By incorporating the information structure issue in our model, it would be possible to investigate the generalizability of their results and to study how the reward system should be revised under different informational conditions.

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Appendix A. Proofs of propositions and lemmas

Proof of lemma 1. Suppose \((R_1, \ldots, R_n)\) is a solution under which the constraint is not binding for some \(i\). Consider a change of the reward function \(R_i\) to a new function \(R_i^\delta\) such that \(R_i - R_i^\delta = \delta > 0\). This new function does not change the worker’s original choice of \(s_i\) as long as \(\delta\) is small enough to satisfy the participation constraint. However, a firm’s net payoff will be higher by \(\delta\) than under \(R_i\). This yields a contradiction. \(\Box\)

Proof of lemma 2. By combining the FOC’s in (6) for worker \(i\) and \(j\), we have

\[
\left\{ \frac{\partial F(s^*_i; k)}{\partial s_i} - \frac{\partial F(s^*_j; k)}{\partial s_j} \right\} + \left\{ \frac{\partial P(k_i - s^*_i)}{\partial s_i} - \frac{\partial P(k_j - s^*_j)}{\partial s_j} \right\} - \left\{ C'(s^*_i) - C'(s^*_j) \right\} = 0. \tag{A.1}
\]

(1) Case 1: \(k_i = k_j = k\). First, consider the case \(PK_i > PK_j\). Suppose that \(s^*_i \leq s^*_j\). Then, the sign of the second and the last parentheses in (A.1) is non-negative and non-positive, respectively. Therefore, the first parentheses should be non-positive to satisfy (A.1). However,

\[
\frac{\partial F(s^*_i, s^*_j; k, k)}{\partial s_i} \geq \frac{\partial F(s^*_i, s^*_j; k, k)}{\partial s_j} \geq \frac{\partial F(s^*_i, s^*_j; k, k)}{\partial s_j}, \tag{A.2}
\]

which yields a contradiction.\(^{17}\) Thus, \(s^*_i > s^*_j\).

Second, suppose \(PK_i = PK_j\). Then, by the symmetry, \(s^*_i = s^*_j\).

(2) Case 2: \(k_i > k_j\). Suppose that \(s^*_i \leq s^*_j\). Then, as in case 1, the sign of the first parentheses in (A.1) should be negative to satisfy the FOC. Here, the following relationships hold:

\[
\frac{\partial F(s^*_i, s^*_j; k_i, k_j)}{\partial s_i} = \frac{\partial F(s^*_i, s^*_j; k_i, k_j)}{\partial s_j} \geq \frac{\partial F(s^*_i, s^*_j; k_i, k_j)}{\partial s_j}. \tag{A.3}
\]

\(\Box\) Subcase 1: Zero interdependence. Under zero interdependence, the following equalities hold:

\[
\frac{\partial F(s^*_i, s^*_j; k_i, k_j)}{\partial s_j} = \frac{\partial F(s^*_i, s^*_j; k_i, k_j)}{\partial s_j}. \tag{A.4}
\]

If \(PK_j \geq PK_i\), then \(\partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_i \geq \partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_j\). Therefore, from (A.3) and (A.4), \(\partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_i \geq \partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_j\), which leads to a contradiction. Therefore, \(s^*_i > s^*_j\). If \(PK_j < PK_i\), then \(\partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_i < \partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_j\). By (A.3) and (A.4), \(\partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_i - \partial F(s^*_i, s^*_j; k_i, k_j)/\partial s_j\) can

\(^{17}\) Other arguments for \(k (\neq i \text{ or } j)\) of the function \(F\) were omitted for simplicity of notation. The inequalities follow from the concavity of \(F\), the productivity of \(i\) and \(j\), and the interdependence, respectively.
be negative for a large difference of productivity. While (A.1) would not hold in most cases leading to \( s_i^* > s_j^* \), it can hold (that is, \( s_i^* \leq s_j^* \)) for a very large productivity difference.

\( \square \) Subcase 2: Positive interdependence. In this subcase, (A.4) changes as follows:

\[
\frac{\partial F(s_i^*, s_j^*; k_i, k_j)}{\partial s_j} > \frac{\partial F(s_i^*, s_j^*; k_i, k_j)}{\partial s_j} < \frac{\partial F(s_i^*, s_j^*; k_i, k_j)}{\partial s_j}. \tag{A.5}
\]

If \( PK_i \geq PK_j \), then from (A.3) and (A.5), \( \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_i \geq \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_j \) is likely to hold, as long as the interdependence is not very strong or \( k_i \) is not very different from \( k_j \) that is, \( \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_i - \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_j \) is not very large (the second inequality in (A.5)). This leads to \( s_i^* > s_j^* \) in most cases. If \( PK_i < PK_j \), then \( \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_i < \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_j \). From (A.3) and (A.5), \( \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_i - \partial F(s_i^*, s_j^*; k_i, k_j)/\partial s_j \) can be negative for a large difference of productivity and low interdependence. While (A.1) would not hold in most cases, leading to \( s_i^* > s_j^* \), it may hold (that is, \( s_i^* \leq s_j^* \)) for a very large productivity difference. \( \square \)

Proof of lemma 3. Under GBR, (A.1) is changed as follows:

\[
c\left\{ \frac{\partial F(s^*)}{\partial s_i} - \frac{\partial F(s^*)}{\partial s_j} \right\} + \left\{ \frac{\partial P(k_i - s^*)}{\partial s_i} - \frac{\partial P(k_j - s^*)}{\partial s_j} \right\} - \left\{ C'(s^*) - C'(s^*) \right\} = 0. \tag{A.6}
\]

The inclusion of a positive coefficient \( c \) does not change any of the proof of lemma 2. \( \square \)

Proof of part (i) of proposition 3. To examine the effect of \( \lambda \) and \( \mu \) on the net payoff, let us derive a reward, \( R_i^{2*} \) that leads to \( s_i^{1*} \) under \( \lambda_2 \). The worker’s FOC under \( \lambda_2 \) and \( R_i^{2*} \) is

\[
\frac{1}{\lambda_2} \frac{\partial P(k_i - s_i)}{\partial s_i} - \frac{1}{\mu} C'(s_i) + \frac{\partial R_i^{2*}}{\partial s_i} = 0. \tag{A.7}
\]

Since \( s_i^{1*} \) satisfies

\[
\frac{\partial F(s_i^{1*})}{\partial s_i} + \frac{1}{\lambda_1} \frac{\partial P(k_i - s_i^{1*})}{\partial s_i} - \frac{1}{\mu} C'(s_i^{1*}) = 0, \tag{A.8}
\]

from (A.7) and (A.8), and the participation constraints,

\[
R_i^{2*} = \left\{ \frac{\partial F(s_i^{1*})}{\partial s_i} + \frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right\} s_i + \frac{1}{\lambda_2} \{ P(k_i) - P(k_i - s_i^{1*}) \}
+ \frac{1}{\mu} C(s_i^{1*}) - \left\{ \frac{\partial F(s_i^{1*})}{\partial s_i} + \frac{1}{\lambda_1} - \frac{1}{\lambda_2} \frac{\partial P(k_i - s_i^{1*})}{\partial s_i} \right\} s_i^{1*}. \tag{A.9}
\]

Denote \( R_i^{1*} \) and \( \pi_i^{1*} \) as the reward and the net payoff at the optimum under \( \lambda_j \). Since

\[
R_i^{2*}\big|_{s_i=s_i^{1*}} = \frac{1}{\lambda_2} \{ P(k_i) - P(k_i - s_i^{1*}) \} + \frac{1}{\mu} C(s_i^{1*}) < R_i^{1*} = \frac{1}{\lambda_2} \{ P(k_i) - P(k_i - s_i^{1*}) \} + \frac{1}{\mu} C(s_i^{1*}), \tag{A.10}
\]

\[
\pi_i^{1*} = F(s_i^{1*}) - \sum_i R_i^{1*} < \pi_i^{2*} = F(s_i^{1*}) - \sum_i R_i^{2*}\bigg|_{s_i=s_i^{1*}} \leq \pi_i^{1*}. \tag{A.11}
\]

Therefore, as \( \lambda \) increases, the net payoff also increases. The same result is obtained for \( \mu \). The above analysis is also easily extended to GBR, and similar results are derived. \( \square \)

Proof of part (i) of proposition 4. By comparing (19) with (20),

\[
R_i = \frac{\partial F(s^*)}{\partial s_i} s_i + P(k_i) - P(k_i - s_i^*) + C(s_i^*) - \frac{n-1}{n} s_i^* - \frac{\partial F(s^*)}{\partial s_i} s_i^*. \tag{A.12}
\]
is incentive compatible. Let us denote $s_i^*$ and $s_o^*$ as optimal knowledge sharing under $\xi_1$ and $\xi_2(>\xi_1)$, respectively. Similar to the analysis for $\lambda$, a reward $(R_i^{2*})$ that leads to $s_i^*$ under $\xi_2$ is derived as follows:

$$R_i^{2*} = \left\{ \frac{\partial F(s_i^*)}{\partial s_i} + (\xi_1 - \xi_2 + \frac{n - 1}{n}) s_i + P(k_i) - P(k_i - s_i^*) + C(s_i^*) - \xi_2 \frac{n - 1}{n} s_i^* \right\}$$

$$- \left\{ \frac{\partial F(s_i^*)}{\partial s_i} + (\xi_1 - \xi_2 + \frac{n - 1}{n}) s_i^* \right\}.$$  \hspace{1cm} (A.13)

Denote $R_i^{2*}$ and $\pi^*$ as the reward and net payoff at $s_i^*$. Since $R_i^{2*} < R_i^{1*}$ from (A.12) and (A.13), $\pi^{1*} < \pi^{2*} \leq \pi^{2*}$. For GBR, the same results can be obtained through a similar analysis. \hfill \Box

**Appendix B. Functional forms and solutions of the numerical examples**

The following specific functions were used for the numerical examples in Figs. 1 and 2 in the text:

$$F(s) = \sum_i (x_i/2)(v_i^2 - (v_i - s_i)^2) \sum_{j \neq i} k_j + \sum_i \sum_{j \neq i} \beta_{ij} s_i s_j,$$

$$v_i \geq k_i, x_i > 0 \text{ and } \beta_{ij} > 0 \text{ for all } i \neq j. \hspace{1cm} (A.14)$$

$$P(k_i) = (\gamma/2)(u^2 - (u - k_i)^2), \hspace{0.5cm} \gamma > 0 \text{ and } u \geq k_i \text{ for all } i. \hspace{1cm} (A.15)$$

$$C(s_i) = (\delta/2)s_i^2, \hspace{0.5cm} \delta > 0. \hspace{1cm} (A.16)$$

Since

$$\frac{\partial F(s)}{\partial s_i} = x_i(v - s_i) \sum_{j \neq i} k_j + \sum_{j \neq i} \beta_{ij} s_j,$$

as $x_i$ and $\beta_{ij}$ increase, the productivity of $s_i$ increases. Therefore, they together capture the productivity of knowledge. In addition, since $\frac{\partial^2 F(s)}{\partial s_i \partial s_j} = \beta_{ij}$, $\beta_{ij}$ represents the interdependence of knowledge between worker $i$ and worker $j$. $\gamma$ and $\delta$ are related to the importance of power and the importance of time and effort, respectively.

Next, the derivation of the IBR in Proposition 1 is illustrated using the above functions in the following. The illustration is for the two worker case $(n = 2)$ to spare the space. The same steps can be applied for more than two workers cases.

Since $P(k_i - s_i)/\partial s_i = -\gamma(u - k_i + s_i)$ and $C'(s_i) = \delta s_i$, the FOC for worker $i$ in (6) is as follows:

$$a_i k_{3-i} (v_i - s_i) + \beta_{12} s_{3-i} - \gamma (u - k_i + s_i) - \delta s_i = 0, \hspace{0.5cm} i = 1, 2. \hspace{1cm} (A.17)$$

By solving the two FOC's in (A.17) simultaneously, we have the optimal knowledge sharing amount,

$$s_i^* = \frac{x_i (x_i - \gamma) k_i^2 + (x_i x_{3-i} v_i k_{3-i} + x_{3-i} k_{3-i}^2 + (x_i \gamma k_{3-i} - (x_i - u - \gamma - \delta)\gamma) k_i + (x_i \gamma u + \gamma + \delta) k_{3-i} - (\beta_{12} + \gamma + \delta) u)}{(x_i \gamma k_{3-i} + (x_i \gamma u + \gamma + \delta) k_{3-i} - (\beta_{12} + \gamma + \delta) u)}, \hspace{0.5cm} i = 1, 2. \hspace{1cm} (A.18)$$

By inserting $s_i^*$ into $\frac{\partial F(s)}{\partial s_i}$, $P(k_i - s_i)$, and $C(s_i)$, we have the marginal reward $a_i = \frac{\partial F(s^*)}{\partial s_i}$, and the base reward $b_i = P(k_i) - P(k_i - s_i^*) + C(s_i^*) - (\frac{\partial F(s^*)}{\partial s_i}) s_i^*$. The detailed expression of the reward function is omitted.

Finally, the optimal GBR for (P4) in the text can be derived in the following steps: First, for any given marginal reward $c$, each worker’s choice of knowledge sharing amount is determined by the FOC in (13). By solving the FOC’s for all workers simultaneously, the knowledge sharing amounts under the marginal reward $c$ are derived. Next, the corresponding base reward $d$ is derived from (14). Then, the net payoff under this GBR can be calculated from the net payoff function in (11). The same steps are repeated for varying values of the marginal reward, and we can find the optimal GBR which maximizes the net payoff.
References


