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Encouraging knowledge sharing in engineering firms—part II: game theory analysis and firm strategies

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Encouraging knowledge sharing is the cornerstone of a successful knowledge management system. This paper follows an earlier study that identified incentives and disincentives for knowledge sharing between individual employees in engineering firms and developed contingent assumptions that the contextual factors of firm size and task repetitiveness impact these dynamics. This paper expands on these results using game theory modelling and analysis. Research on intra-organizational knowledge sharing requires an understanding of why and when individuals are willing to share their knowledge; as a result, game theory modelling is ideal for modelling these dynamics and deriving knowledge-sharing strategies. Based on the modelling results, a set of contingent strategies for encouraging knowledge sharing are developed. The results of this study shed light on the knowledge-sharing interactions between individual employees and develop strategies for firms to more efficiently and effectively encourage the sharing of valuable knowledge.

Keywords: Game theory, knowledge management, knowledge sharing, organization, strategy.

Introduction

Firms would like to transfer and mobilize knowledge across them as it can lead to improved productivity (Dyer and Nobeoka, 2000), performance (Haas and Hansen, 2007) and other capabilities. However, many firms are still struggling with how to transfer and mobilize knowledge effectively. As a result, the objective of this research is to add to the emerging literature of knowledge management (KM) by deriving a contingency view of how to effectively promote knowledge sharing. In previous work, we identified incentives and disincentives for knowledge sharing between employees. In addition, we identified firm characteristics, including size and task repetitiveness, that may impact these incentives. This paper, Part II, expands on the results obtained from Part I to construct a game theory model, solve the game model equilibrium solutions and derive contingent strategies that encourage knowledge sharing.

Game theory was selected for the research because the sharing of knowledge relates to the competitive and cooperative relationships between employees. In this paper, we develop a game theory model and solve for the conditions that determine the knowledge-sharing behaviours of individual employees. Based on the modelling and analysis, we propose a contingency framework that suggests three contingent strategies for reinforcing the sharing behaviours in different organizational contexts. Lastly, we derive three testable hypotheses based on the proposed contingency framework.

Research approach

Our multi-method research approach uses past results from ethnographic case studies and literature review reported in Part I to analyse the interactive knowledge-sharing dynamics between individual employees

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using game theory modelling. In construction and engineering research, game theory analysis and modelling have been applied to develop strategies for subcontractor selection (Unsal and Taylor, 2011), to analyse cooperative (Eriksson, 2007) and opportunistic bidding (Ho and Liu, 2004) behaviours, to build theories of governance strategies in public–private partnerships (Ho, 2005, 2006) and to build strategies concerning investment decisions for KM programmes (Ho *et al.*, 2011). The ethnographic case studies and literature review in Part I help to form model variables and contextual assumptions for game theory modelling conducted in this study.

Game theory can be defined as 'the study of mathematical models of conflict and cooperation between intelligent rational decision-makers' (Myerson, 1991). Game theory has been applied to many important topics in economics (Mas-Colell *et al.*, 1995). 'Games' can be classified by the completeness of information and the way in which games are played. There are two basic types of games: static games and dynamic games. In a static game, the players act simultaneously, meaning that each player chooses his or her action without knowing the decisions of others. In contrast, in a dynamic game, players act sequentially and observe other players' actions in previous moves. In this study, as we shall explain later, dynamic games are used to model knowledge sharing between employees.

In order to determine how each player will behave in a game, we need to determine the 'Nash equilibrium' (NE), a set of strategies, each of which determines the optimal response exhibited by each player, given other players' strategies in the equilibrium. Because the strategies in the NE are the best possible responses exhibited by each player based on the decisions of others, the set of strategies can be viewed as a stable equilibrium. In other words, in an NE, no player can increase its payoff by unilaterally deviating from the equilibrium solution. Thus, the equilibrium is 'strategically stable' and 'self-enforcing' (Gibbons, 1992).

Game theory modelling for strategic management purposed generally consists of three steps. The first step is to abstract the problem under study and develop a game model. Doing this requires sufficient knowledge of the problem to make appropriate assumptions to simplify the problem and focus on a few critical components. The results presented in the previous study (reported in the Part I paper) regarding the incentives and disincentives for knowledge sharing provide the basis for problem abstraction in this study. The second step is to solve for the conditions of all the possible or specific solutions of the game model. The number of possible equilibria and the complexity of the equilibrium solutions depend on the complexity of the game model and the number of variables for the players' payoffs. The third step is to derive strategy implications or build a new theory by identifying possible variables of strategic importance, called 'contextual variables', and then link the contextual variables to model solutions. When the equilibrium solution is complicated, identifying possible contextual or situational variables can narrow down the possible solution space and provide additional insights to help understand the problem. Once the logic between different contingencies and possible equilibria is established, a new theory can be built from the logic.

The game model of knowledge sharing between individual employees

In this section, we first discuss the setup of the model and present the game tree that represents the model. Then, we solve the equilibrium solutions of the game model and discuss the meanings of these equilibria. Note that the equilibrium solutions of the game model section involves technical details that may be arcane for readers without game theory background; such readers may choose to skip the technical details and equations and, instead, focus only on the possible equilibria and the conditions for each NE, as summarized in Table 1.

Model variables

The formation of model variables is based on literature review and the insights obtained from the case studies as presented in Part I of the companion papers. The incentives and disincentives for knowledge sharing serve as the payoff variables for modelling. Here, we recapitulate the definition of and the underlying rationale for each model variable.

A: Self-satisfaction from knowledge sharing

When sharing useful knowledge, the sharers may feel very positively about helping others, being a valuable person to the firm or their self-images. Such self-satisfaction can be an important intrinsic payoff due to altruistic motivations or the pure enjoyment of certain 'meaningful' activities.

B_s: Benefits from increased professional reputation due to sharing knowledge

The increased professional reputation is associated with career development in terms of promotion and professional authority. Thus, being recognized as experts by peers and the firm can be an important motivator for knowledge sharing.

B_o: *Benefits of receiving knowledge from others in a firm*

The benefits of receiving knowledge from others are also associated with the sharer's career advancement through better work performance. This is particularly true in firms with repetitive tasks, where the past experiences of other colleagues can be reutilized in future projects. In addition, individual employees can benefit from others by learning new work-related knowledge. Collectively, the firms can benefit from increased organizational knowledge and thus performance.

R_1: *Social rewards from knowledge sharing*

One of the most frequently discussed motivations for sharing knowledge is social motivation, such as reciprocity or conformity to a corporate culture and expectations. Social rewards are the intrinsic payoffs generated through social mechanisms. Examples may include being recognized as a good community citizen or being welcomed or appreciated by others.

The avoidance of R_2, *the social punishment faced due to withholding knowledge*

From neuro-economics perspective, humans tend to impose punishment on individuals who exhibit anti-social behaviours such as 'free-riding' or not being a good citizen of a society. The strong form of reciprocity, emphasizing the social obligation to repay others for what a person has received, is one of the most persuasive social forces. Therefore, we assume that the avoidance of social punishment, R_2, can be an important incentive for knowledge sharing.

C: The costs of knowledge sharing

The costs of knowledge sharing are assumed to be the major disincentive for knowledge sharing. According to Ho *et al.* (2011), individuals face two types of costs associated with knowledge sharing: the explicit costs and the implicit costs. The explicit costs refer to the time and effort needed to share knowledge. Explicit costs are usually higher when the shared knowledge is more complex or tacit. The implicit costs of sharing are due to the indirect negative consequences that employees experience when they share their knowledge. In particular, if an employee possesses 'unique' valuable knowledge or worries about competition from other colleagues, the employee's implicit sharing costs will be high. For modelling convenience, we combine the explicit costs and implicit costs into one single variable, C. However, it is crucial to remember that, conceptually, C consists of the two different types of costs discussed.

Model setup and the game tree

Figure 1 shows the game model of the knowledge-sharing interactions in a firm. The knowledge-sharing dynamics between two employees are modelled by a two-person game. As shown in Figure 1, Employee 1 is labelled as Player 1 and Employee 2 is labelled as Player 2. Payoffs are modelled for three scenarios and the payoff profiles, denoted as (payoffs for Player 1, payoffs for Player 2), are shown for each player at the end of the branch. The three scenarios are described below.

Scenario 1

When both players share their knowledge, both are rewarded by the benefits of increased professional reputation, B_s, the benefits of receiving knowledge shared by the other, B_o, social rewards due to sharing, R_1, and self-satisfaction, A. Meanwhile, their rewards are also partially offset or even outweighed by the efforts and implicit costs required to share their knowledge, C.

Scenario 2

When knowledge sharing is one sided, that is, only one player shares, the sharer is rewarded by B_s, R_1 and A. In this scenario, the sharer does not receive new knowledge, B_o; however, he or she still exerts efforts to share his or her knowledge with the free-rider, C. The other player, the free-rider, obtains new knowledge, B_o, for zero costs; however, he or she may also receive social punishment, R_2, from members of the organization.

Scenario 3

When neither of the players shares his or her knowledge, he or she ends up with zero positive payoffs and zero cost for sharing. Note that there will not be social punishment if no one shares because, if no one shares, free-riding would not exist and social punishment would not be imposed.

In this study, we use a dynamic game of perfect information to model and abstract the interactions between firm employees. Dynamic games are used for modelling because (1) players are assumed to be able to observe others' actions and (2) the game involves sequential interactions between employees. From the one-shot static game perspective, it is certainly difficult for employees to clearly identify who is withholding knowledge. However, since the sharing interactions in practice are a repeating process of this one-shot game, it is not difficult to know who is sharing knowledge and who is not in a given period of time. This is especially true with today's information

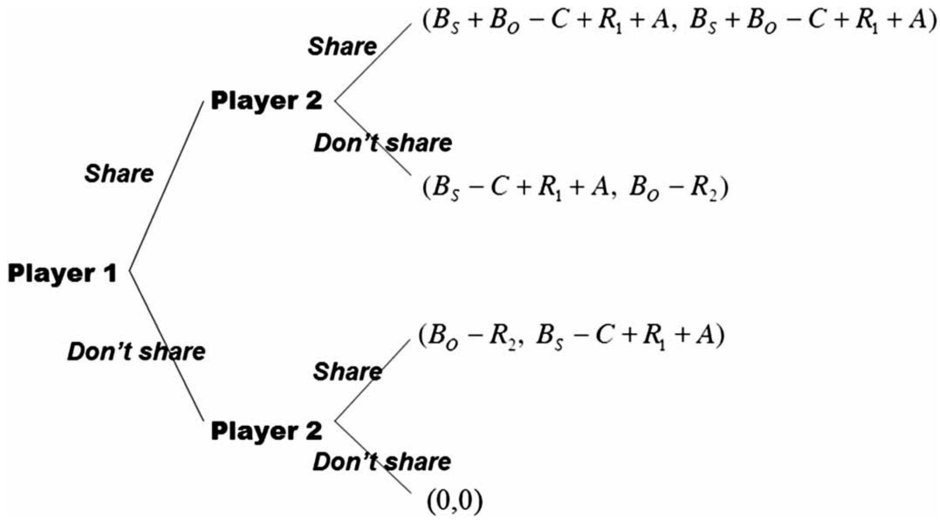

Figure 1 Game tree

technologies and KM platform designs, where it is easy to observe the frequency and quality of individual employee's knowledge sharing. Thus, it is reasonable to use a dynamic game model by assuming that each individual can easily observe whether other individuals in the firm share their knowledge. Also note that although it seems difficult to precisely quantify the value of every model variable concerning sharing payoffs, practically, most people should be able to subjectively assess or determine the comparative magnitudes of the overall payoffs of different situations to determine the better decision. Thus, as in most game theory applications, we assume that the sharing payoffs are common knowledge and known to all players.

Furthermore, whereas it may seem restrictive to have only two players in the model, we argue that it is not as restrictive as it may seem. In an organization, it 'cannot be certain' who will use whose shared knowledge. Eventually, knowledge shared by anyone can help any other individual. From this perspective, it is reasonable to use the two-player abstraction by assuming that anyone who shares or does not share may affect the other player in the model, without resorting to a complicated network model of interaction. This simplification greatly reduces the model's complexity and improves its tractability. However, we do acknowledge the existence of potential limitations due to this simplification.

Equilibrium solutions of the game model

We obtain four possible equilibria for the model. We solve the game backward by first analysing Player 2's choice of strategies. Player 2's possible strategies are categorized into four cases, including Case I, 'always share'; Case II, 'be a follower'; Case III, 'never share'; and Case IV, 'do the opposite'. In the following analysis, we use [Player 1's action, Player 2's action] to represent decisions taken by two players. For example, we use [Share, Don't Share] to represent [Player 1 shares his knowledge, but Player 2 doesn't]. The conditions required by each equilibrium solution are summarized in Table 1.

Equilibria of Case I

In Case I, Player 2 'always shares'. If Player 2 always shares, the possible equilibrium path will be [Share, Share] or [Don't Share, Share]. For Player 2 to 'always share', the payoffs for choosing 'Share' must

Table 1 Required conditions for each game equilibrium

	Equilibrium conditions
Equilibrium #1	[Share, Share]
	• $B_s - C + R_1 + A > 0$ (Equation 2)
Equilibrium #2	[Share, Share]
	• $R_2 < B_s - C + R_1 + A < 0$ (Equation 7)
	• $B_s - C + R_1 + A > -B_o$ (Equation 8)
	• $R_2 >> 0$ (Equation 10)
	• $B_o >> 0$ (Equation 11)
Equilibrium #3	[Don't Share, Don't Share]
	• $-R_2 < B_s - C + R_1 + A < -B_o$ (Equation 12)
	• $R_2 >> B_o >\sim 0$ (Equation 13)
Equilibrium #4	[Don't Share, Don't Share]
	• $R_2 > B_s - C + R_1 + A$ (Equation 14)
	• $R_2 >\sim 0$ (Equation 18)

be greater than the payoffs for choosing 'Don't Share', regardless of Player 1's choice. As a result, the following two conditions have to be satisfied:

$$B_s + B_o - C + R_1 + A > B_o - R_2 \rightarrow B_s - C + R_1 + A > -R_2 \quad (1)$$

$$B_s - C + R_1 + A > 0 \rightarrow B_s - C + R_1 + A > 0 \quad (2)$$

Equations 1 and 2 can be summarized or implied by Equation 2. Next, we solve for Player 1's decision by comparing the respective payoffs of choosing 'Share' and 'Don't Share'. According to the payoffs shown in Figure 1, Player 1 will 'Share' when Equation 3 is satisfied and will choose 'Don't Share' when Equation 4 is satisfied:

$$B_s + B_o - C + R_1 + A > B_o - R_2 \rightarrow B_s - C + R_1 + A > -R_2 \quad (3)$$

$$B_s + B_o - C + R_1 + A < B_o - R_2 \rightarrow B_s - C + R_1 + A < -R_2 \quad (4)$$

As a result, the first possible equilibrium of the game, *Equilibrium #1*, following [Share, Share], is obtained when Equations 2 and 3 are satisfied. Equations 2 and 3 can be summarized again by Equation 2, $B_s - C + R_1 + A > 0$. Note that [Don't Share, Share] cannot be the equilibrium path since Equations 2 and 4 are contradictory and, thus, cannot be satisfied concurrently.

Equilibria of Case II

In Case II, Player 2's strategy is to 'be a follower'. When Player 2 chooses to 'be a follower', [Share, Share] and [Don't Share, Don't Share] will be the possible equilibrium paths. Similar to the equilibrium-solving procedure in Case I, the following two conditions have to be satisfied for Player 2 to 'be a follower':

$$B_s + B_o - C + R_1 + A > B_o - R_2 \rightarrow B_s - C + R_1 + A > -R_2 \quad (5)$$

$$0 > B_s - C + R_1 + A \rightarrow B_s - C + R_1 + A < 0 \quad (6)$$

Combining Equations 5 and 6, we have

$$-R_2 < B_s - C + R_1 + A < 0 \quad (7)$$

Considering Player 1's sequential rationality and given condition (7), [Share, Share] will be the equilibrium path if Equation 8 is satisfied and [Don't Share, Don't Share] is the path if Equation 9 is satisfied:

$$B_s + B_o - C + R_1 + A > 0 \rightarrow B_s - C + R_1 + A > -B_o \quad (8)$$

$$B_s + B_o - C + R_1 + A < 0 \rightarrow B_s - C + R_1 + A < -B_o \quad (9)$$

The second possible equilibrium, *Equilibrium #2*, following [Share, Share], can be obtained when Equations 7 and 8 are satisfied. Although mathematically the inequality in Equation 7 can be satisfied as long as R_2 is greater than zero, it does not make practical sense for R_2 to be too small. If R_2 were too small, it would make the range $[-R_2, 0]$ too narrow such that the probability of the sum of $(B_s - C + R_1 + A)$ falling in the narrow range is slim. Therefore, for this equilibrium to be practical, we argue that R_2 must be large. As such, we supplement a restriction, Equation 10, for this equilibrium:

$$R_2 >> 0 \quad (10)$$

Note that the conditions for *Equilibrium #2*, Equations 7 and 8, can be summarized by $B_o < B_s - C + R_1 + A < 0$, identical to the structure of Equation 7. Therefore, we add another restriction, Equation 11, for this equilibrium:

$$B_o >> 0 \quad (11)$$

In summary, the conditions for *Equilibrium #2*, following [Share, Share], are Equations 7, 8, 10 and 11, as shown in Table 1.

The third possible equilibrium, *Equilibrium #3*, following [Don't Share, Don't Share], can be obtained when Equations 7 and 9 are satisfied, which can be rewritten as

$$-R_2 < B_s - C + R_1 + A < -B_o \quad (12)$$

Following the same logic for adding restrictions to the previous equilibrium, we add an additional restriction that $R_2 >> B_o$ to ensure that the range $[-R_2, -B_o]$ is not too narrow to be satisfied. In addition, note that although it is possible that $B_o >> 0$, it is unlikely that social punishment would be so large that $R_2 >> B_o >> 0$. Thus, for *Equilibrium #3*, we may add the restriction that $R_2 >> B_o >\sim 0$, where $>\sim$ denotes greater than but close to, in order to prevent R_2 from being unreasonably high:

$$R_2 >> B_o >\sim 0 \quad (13)$$

In summary, the conditions for *Equilibrium #3*, following [Don't Share, Don't Share], are Equations 12 and 13, as shown in Table 1.

The insight from this equilibrium condition is that when the overall payoff due to sharing, $B_s + B_o - C + R_1 + A$, is negative, social punishment cannot facilitate the sharing of knowledge if the benefits of receiving knowledge shared by others are limited. The required conditions for *Equilibrium #3* are summarized in Table 1.

Equilibria of Case III

In Case III, Player 2's strategy is 'never share'. In this case, [Share, Don't Share] and [Don't Share, Don't Share] will be the possible equilibrium paths. First, according to the payoff structure shown in the game tree, the following two conditions have to be satisfied for Player 2 to choose 'never share':

$$B_o - R_2 > B_o + B_s - C + R_1 + A \rightarrow -R_2 > B_s - C + R_1 + A \quad (14)$$

$$B_s - C + R_1 + A < 0 \quad (15)$$

Considering Player 1's sequential rationality and conditions (14) and (15), [Share, Don't Share] is the equilibrium path if Equation 16 is satisfied and [Don't Share, Don't Share] is the equilibrium path if Equation 17 is satisfied:

$$B_s - C + R_1 + A > 0 \quad (16)$$

$$B_s - C + R_1 + A < 0 \quad (17)$$

Note that no equilibrium will follow [Share, Don't Share] in Case III since conditions (15) and (16) are contradictory. However, we can obtain the fourth equilibrium, *Equilibrium #4*, following [Don't Share, Don't Share], when Equations 14, 15 and 17 are satisfied. The three equations can be summarized by Equation 14. Note that when Equation 14 is compared with the conditions for *Equilibrium #2* and *Equilibrium #3*, we may add a further restriction for *Equilibrium #4* that R_2 is close to zero, because if R_2 is large, then Equation 7 for *Equilibrium #2* and Equation 9 for *Equilibrium #3* are more likely to be satisfied. Thus, the revised conditions for *Equilibrium #4* are Equation 14 and the added restriction, Equation 18, as summarized in Table 1:

$$R_2 > \sim 0 \quad (18)$$

Equilibria of Case IV

In Case IV, Player 2 will always 'do the opposite' of Player 1's choice of action. Given this scenario, [Share, Don't Share] and [Don't Share, Share] will be the possible equilibrium paths for the equilibria. For Player 2 to always do the opposite of Player 1's choice of action, the following two conditions have to be satisfied:

$$B_o - R_2 > B_s + B_o - C + R_1 + A \rightarrow -R_2 > B_s - C + R_1 + A \quad (19)$$

$$B_s - C + R_1 + A > 0 \quad (20)$$

Note that since Equations 19 and 20 contradict each other, the equilibrium paths in Case IV cannot lead to any equilibrium.

Insights based on model equilibria

Based on the model equilibria, two important insights concerning individuals' knowledge sharing are induced. In this section, we discuss the meanings and applications of the two insights because these insights are not intuitively obvious.

$B_s - C + R_1 + A$: the strong condition for sharing

According to the equilibrium conditions, an important indicator of our analysis is the combination of four variables, '$B_s - C + R_1 + A$', where B_s, R_1 and A are the benefits of sharing due to increased professional reputation, social rewards and self-satisfaction, respectively, and C are the explicit and implicit costs of sharing. $B_s - C + R_1 + A$, conceptually, is the basic payoff for a sharer, not considering the benefits due to others' sharing. Thus, if $B_s - C + R_1 + A$ is greater than 0, that is, condition (2) is satisfied, the [Share, Share] equilibrium path will be reached without the need for any other conditions. In this paper, we call this condition 'the strong condition for sharing', where 'strong' indicates that this condition is the most stringent condition for the [Share, Share] equilibrium path. If the strong condition for sharing is not satisfied, [Share, Share] can still be obtained by imposing other requirements as shown in *Equilibrium #2*. In *Equilibrium #2*, the additional requirements are that both B_o and R_2 are large enough. In other words, the benefits of receiving knowledge shared by others and the social punishment faced due to withholding knowledge will restore the dynamics back to [Share, Share] when the strong condition for sharing is not satisfied.

The effectiveness of strong reciprocity

In addition to the social rewards, R_1, culture and social norms for reciprocity can also add social punishment, R_2, to the payoffs due to the 'strong reciprocity' phenomenon discussed earlier. By contrasting *Equilibrium #2* for [Share, Share] and *Equilibrium #3* for [Don't Share, Don't Share], we may conclude that the social punishment for withholding knowledge, R_2, will only be effective when the benefits of receiving knowledge shared by others are large enough. Otherwise, *Equilibrium #3* following [Don't Share, Don't Share] will be the solution since [Don't Share, Don't Share] prevents employees from negative payoffs and, at the same time, the players will not be penalized socially when no employees share. We may also conclude that when the strong condition for sharing is not satisfied, strong reciprocity becomes the necessary, but not the sufficient, condition for [Share, Share], as indicated by the conditions for *Equilibrium #4*.

Refined equilibria, the implied contingent strategies and testable hypotheses

Considering the two aforementioned contextual variables that can be used to characterize a firm, the relative magnitude of three variables, B_s, B_o and C, can be determined so as to obtain more managerially useful model solutions. We use {Firm size, Nature of tasks} to represent four possible different contextual situations. Tables 2 and 3 summarize the refined NEs and the implied contingent strategies, respectively. Detailed derivations and discussions follow.

Contextual variables and assumptions

Organizational characteristics may have crucial impacts on the micro-level payoff variables. These organizational or situational factors are called 'contextual variables' in this paper. Contextual assumptions concerning how the contextual variables affect individuals' payoff variables are made to refine the game solutions. By considering the contextual assumptions, equilibria obtained earlier can be transformed into new sets of equilibria that are contingent on different contextual situations. These new equilibria are useful for deriving organizational strategies to encourage knowledge sharing. Based on the insights from case studies, two contextual variables, discussed next, are identified for refining the game model. In our prior work, reported in the Part I

Table 2 Refined equilibrium solutions considering the contextual variables

	Large firm (small C, large B_s)	Smaller firm (larger C, smaller B_s)
Repetitive tasks (large B_o)	Small C and large $B_s \rightarrow B_s - C + R_1 + A > 0$ NE path is • [Share, Share]: NE #1 $B_s - C + R_1 + A > 0$ (Equation 2)	Larger C and smaller $B_s \rightarrow B_s - C + R_1 + A < 0$ NE paths are • [Share, Share]: NE #1 If *$R_1 + A$ is large* $\rightarrow B_s - C + R_1 + A > 0$ (Equation 2) • [Share, Share]: NE #2 If *$R_1 + A$ is small but R_2 is large* $\rightarrow -R_2 < B_s - C + R_1 + A < 0$ (Equation 7) $B_s - C + R_1 + A > -B_o$ (Equation 8) $R_2 >> 0$ (Equation 10) $B_o >> 0$ (Equation 11) • [Don't Share, Don't Share]: NE #4 If *both $R_1 + A$ and R_2 are small* $\rightarrow -R_2 > B_s - C + R_1 + A$ (Equation 14) $R_2 >\sim 0$ (Equation 18)
Less repetitive tasks (smaller B_0)	Small C and large $B_s \rightarrow B_s - C + R_1 + A > 0$ NE path is • [Share, Share]: NE #1 $B_s - C + R_1 + A > 0$ (Equation 2)	Larger C and smaller $B_s \rightarrow B_s - C + R_1 + A < 0$ NE paths are • [Share, Share]: NE #1 If *$R_1 + A$ is large* $\rightarrow B_s - C + R_1 + A > 0$ (Equation 2) • [Don't Share, Don't Share]: NE #3 If *$R_1 + A$ is small but R_2 is large* $\rightarrow -R_2 < B_s - C + R_1 + A < -B_o$ (Equation 12) $R_2 >> B_o >\sim 0$ (Equation 13) • [Don't Share, Don't Share]: NE #4 If *both $R_1 + A$ and R_2 are small* $\rightarrow -R_2 > B_s - C + R_1 + A$ (Equation 14) $R_2 >\sim 0$ (Equation 18)

Table 3 Contingent strategies for encouraging knowledge sharing

	Large firm	Smaller firm
Repetitive tasks	• Be an expert strategy • Be a good person strategy	• Be a good person strategy • Be a good citizen strategy
Less repetitive tasks	• Be an expert strategy • Be a good person strategy	• Be a good person strategy

paper, firm size and firm task repetitiveness were identified as the main contextual variables. Contextual assumption #1 concerning firm size suggests that the implicit costs of sharing in large firms than in smaller firms are generally much smaller and the reputational benefits due to sharing one's own knowledge are generally much greater. Contextual assumption #2 concerning task repetitiveness hypothesizes that individual employees working for companies that primarily perform unique, less-repetitive tasks receive fewer benefits from the knowledge shared by others, B_o, whereas employees working for companies that primarily perform repetitive work receive more benefits from the knowledge shared by others.

Equilibria and implied strategies for {Large Firms, Repetitive Tasks}

Given the contextual assumption #1 that individuals in large companies will have much smaller costs, C, and larger reputational benefits, B_s, *Equilibrium #1* following [Share, Share] will be the refined equilibrium as shown in Table 2 because Equation 2, $B_s - C + R_1 + A > 0$, the strong condition for sharing, is generally satisfied due to the contextual assumption. This equilibrium can be further reinforced when the intrinsic rewards, $R_1 + A$, are not too small. Therefore, employees in firms characterized by large firm size and repetitive tasks will tend to choose to 'Share'.

While intrinsic rewards due to $R_1 + A$ are generally helpful in encouraging the sharing of knowledge, for large firms, it is very important to create an environment that ensures a high B_s. For example, employees who share valuable knowledge that helps others should be rewarded through proper recognition mechanisms such as giving special 'expert' titles. With such titles, the sharers will automatically enjoy higher visibility and, as a result, have a better chance for future promotion. Alternatively, formal or informal policies on promoting employees who are honoured by expert titles will also help to increase the perceived value for B_s. In this paper, we refer to this strategy as the 'be an expert strategy', one of the contingent strategies summarized in Table 3. In addition, the small C and large B_s in large firms may not guarantee the satisfaction of the strong condition for sharing discussed earlier. Thus, large firms should not ignore the importance of the intrinsic rewards from sharing.

Equilibria and implied strategies for {Large Firms, Less Repetitive Tasks}

On the one hand, when the firm is relatively large, the strong condition for sharing for *Equilibrium #1* will generally be satisfied as discussed in the previous scenario; on the other hand, the degree of task repetitiveness does not affect any variables in Equation 2 and, thus, Equation 2 remains satisfied. Therefore, as shown in Table 2, *Equilibrium #1* remains the solution for this contextual situation and 'be an expert strategy' the implied knowledge-sharing strategy.

Equilibria and implied strategies for {Smaller Firms, Repetitive Tasks}

As shown in Table 2, there are three possible equilibria for smaller organizations with repetitive tasks. First, with a larger C and a smaller B_s often presented in smaller firms, the strong condition for sharing, $B_s - C + R_1 + A > 0$, for *Equilibrium #1* following [Share, Share] generally cannot be satisfied. However, when the intrinsic rewards, $R_1 + A$, for sharing knowledge are large enough, the strong condition for sharing can be satisfied, causing employees to share. Second, given that the benefits from learning others' knowledge, B_o, are large, when a firm has repetitive tasks, conditions for *Equilibrium #2* following [Share, Share], that is, Equations 7, 8, 10 and 11, can be satisfied provided that the social punishment for not sharing, R_2, is significant. The insight of this equilibrium is that smaller firms with repetitive tasks should focus on having a larger value for R_2, social punishment, which will restore the equilibrium path back to [Share, Share]. Third, following the previous discussion, when the strong condition for sharing is not satisfied, *Equilibrium #4* following [Don't Share, Don't Share] will be obtained if R_2 is close to zero. In summary, for {Smaller firms, Repetitive tasks}, intrinsic rewards and social rewards can be the two major incentives for increasing knowledge sharing between individuals;

thus, firms should focus on these incentives to encourage knowledge sharing.

As implied by *Equilibrium #1*, smaller firms may consider creating an environment that values reciprocity and friendliness among employees to increase the social rewards, R_1. As shown in Table 3, we call this strategy 'be a good person strategy', which emphasizes being a person who helps others. In other words, the strategy is to create the culture of helping each other by sharing knowledge.

Alternatively, as implied by *Equilibrium #2*, smaller firms with repetitive tasks can emphasize a 'stronger' form of reciprocity that imposes a certain degree of social punishment on free-riders who benefit from others' sharing but do not actively share. For example, by tracking one's sharing records and knowledge inquiry frequencies through a KM platform and disclosing such information within a firm, it is easy to generate pressure on those who are benefiting from others' sharing but reserving their sharing efforts. The strategy is, therefore, to establish a normative institution of taking the responsibility in sharing knowledge as an organization citizen. We refer to this strategy 'be a good citizen strategy'.

Note that the 'be a good person strategy' and 'be a good citizen strategy' are not exclusive. The two strategies can be adopted simultaneously so that employees can be motivated to share by either one of the strategies or both depending on the characters of individual employees.

Equilibria and implied strategies for {Smaller Firms, Less Repetitive Tasks}

There are also three equilibria in this case. Similar to the previous scenario for smaller firms, with repetitive tasks, *Equilibrium #1* following [Share, Share] can be obtained only when the intrinsic rewards, $R_1 + A$, for sharing are large enough. If the intrinsic rewards are not large enough, *Equilibrium #4* following [Don't Share, Don't Share] will be obtained. Therefore, the 'be a good person strategy' continues to be effective for encouraging knowledge sharing.

However, in contrast to the previous scenarios, since B_o is relatively small, Equation 13 for *Equilibrium #3*, instead of Equation 11 for *Equilibrium #2*, will be satisfied. As a result, although a large R_2 will yield *Equilibrium #2* following [Share, Share], a large R_2 cannot encourage employees to share in the presence of a small B_o. That is, if B_o, the benefits of receiving knowledge from others, are small, even when potential social punishment, R_2, is large, both players will not choose to share. The underlying rationale is that when individuals' total payoffs for sharing are negative, no one will share just to avoid social punishment because social punishment becomes meaningless when no one shares. Strategically speaking, it would be impossible to establish or institutionalize the norm of sharing under this situation. As a result, the 'be a good citizen strategy' becomes ineffective in motivating knowledge sharing given {Smaller firms, Less repetitive tasks}.

Testable hypotheses

Based on the analysis of contingency solutions and implied strategies for knowledge sharing, we develop a theory concerning the effectiveness of various strategies for encouraging knowledge sharing, summarized in Table 3. By comparing the strategies given in Table 3, the proposed theory can be restated as follows. For large firms, the 'be an expert strategy' and 'be a good person strategy' are better for promoting knowledge sharing. For smaller firms with repetitive tasks, the 'be a good person strategy' and 'be a good citizen strategy' are suggested for encouraging knowledge sharing. For smaller firms with less repetitive tasks, the 'be a good person strategy' is the only effective one for knowledge sharing.

Based on the restated strategies, we derive three hypotheses that can be empirically tested for theory verification in future studies. The three hypotheses are as follows:

Hypothesis 1
'Be a good person strategy', a strategy emphasizing intrinsic and social rewards from helping others, is an effective strategy for firms of all types in encouraging knowledge sharing.

Hypothesis 2
'Be an expert strategy', a strategy where firms publicly honour best sharing employees with distinguished expert titles, is more effective for large firms in encouraging knowledge sharing.

Hypothesis 3
'Be a good citizen strategy'—a strategy where firms emphasize the development of social norms of strong reciprocity, including social punishment for knowledge hoarding and social rewards for sharing—is more effective for smaller firms with repetitive tasks in encouraging knowledge sharing.

Conclusions

In this paper, we studied the knowledge-sharing dynamics between employees in a firm and derived strategies that encourage individuals' knowledge sharing. To do this, we developed a game model for analysing the interactive decisions of whether to share knowledge with or hoard knowledge from others.

From the game theory analysis, several important insights were revealed by the possible equilibria obtained. First, we found that as long as the individuals' strong condition for sharing is satisfied, individuals will choose to 'share', no matter what the other players' actions or strategies are. The strong condition for sharing requires that individuals' 'basic' payoffs of sharing minus the costs of sharing are positive, where the basic payoffs do not include the individuals' learning benefits due to others' sharing. Unfortunately, the costs of sharing are often not well balanced by individuals' basic benefits of sharing, causing unwillingness to share knowledge. Second, when the strong condition for sharing is not satisfied, the intrinsic rewards for individuals who share knowledge and/or the social pressure imposed on those who hoard their knowledge may restore the sharing equilibrium, provided that the overall payoffs that include learning from others' shared knowledge are positive. This insight sheds light on the importance of utilizing strategies that emphasize the sharing culture and social norms within an organization. Third, if the overall payoffs are negative, strategies for focusing mainly on the social pressure on free-riders is unlikely to produce sustainable social environments that encourage knowledge sharing.

By further integrating firm size and task repetitiveness as contextual variables for the model, we obtained a set of contingent strategies for encouraging knowledge sharing. First, all firms should consider the 'be a good person strategy', which emphasizes the social and intrinsic rewards due to helping others. Second, in addition to the 'be a good person strategy', large firms should further consider the 'be an expert strategy', a strategy where firms publicly honour best sharers with distinguished expert titles. Finally, in addition to the 'be a good person strategy', smaller firms with repetitive tasks should also consider the 'be a good citizen strategy', a strategy where firms emphasize the development of social norms of strong reciprocity, including social punishment for knowledge hoarding and social rewards for sharing.

This research contributes to theory by developing a contingency view of knowledge-sharing strategies based on the knowledge-sharing dynamics between individuals in a firm. For practitioners, the proposed contingent strategies can help firms choose appropriate strategies for knowledge sharing so as to ensure a more efficient and effective management of their knowledge.

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