Multi-context research on strategy characteristics of knowledge sharing in organization based on dynamic cooperative game perspective

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Abstract

Purpose – *The purpose of this paper is to reveal the characteristics of strategic behavior during knowledge cooperation in organization and compare the differences in strategy choice between knowledge transferor and knowledge receiver under intricate context consisting of two different objective orientations (organizational and individual) and two different information conditions (perfect and imperfect information) that represent different knowledge application contexts (conventional and available knowledge and intricate and personalized knowledge). Moreover, this paper also wishes to develop a new analysis paradigm of dynamic cooperation game to the micro-interactive mechanism research on individuals' knowledge sharing in organization.*

Design/methodology/approach – *Through comparing and referring to previous literatures, and considering the authentic knowledge cooperation practice, this paper first suggested that the behavior characteristics of knowledge sharing between individuals in organization should be observed from the perspective of dynamic cooperation game that would accurately describe the "coopetition" essence of knowledge sharing. Further, an intricate multi-analysis context including two different objective orientations and two different information conditions was constructed. Under this multi-analysis context, the objective functions of knowledge transferor (knowledge output) and knowledge receiver (knowledge returning) were established respectively. Lastly, according to the revenue optimum principle of organizational and individual the strategic choice characteristics were analyzed through the Nash equilibrium to analyze objective functions.*

Findings – *"Knowledge transaction" motive is classic strategic characteristic of individuals' knowledge cooperation, and to increase competitiveness of knowledge sharer is a crucial prerequisite for knowledge sharing under any analysis context combination (no matter organizational or individual objective, no matter perfect or imperfect information). Knowledge sharing appears more conservative and stringent under imperfect information condition, and the effort level of knowledge transferring is strategically adjusted according to the value assessment of received knowledge. The institutional constraints and incentives have little effect on the promotion of knowledge sharing under the imperfect information condition where professional knowledge is more intricate, personalized and implicit, because organization members are more sensitive to knowledge competitiveness.*

Originality/value – *This paper provides a knowledge sharing study with a new analysis paradigm from micro-interactive perspective by aiming at the "coopetition" essence of knowledge cooperation in organization. This analysis paradigm chooses the way of dynamic cooperation game to reveal the strategic characteristics of knowledge sharing among individuals (knowledge transferor and knowledge receiver) and to assess the role of institutional constraints and incentives in promoting the knowledge sharing. At the same time, the establishing of multi-context model with two different perspective dimensions (objective orientation and information condition) make research closer to the authentic circumstance of knowledge cooperation in organization.*

Keywords *Knowledge sharing, Dynamic cooperative game, Multi-context*

Paper type *Research paper*

Received 14 September 2017
Revised 10 October 2017
7 November 2017
Accepted 19 November 2017

The author wishes to thank the NSFC (National Natural Science Foundation Committee of China) for the provision of project funds (project code: 71472090; 71072039) and also the reviewers of *Journal of Knowledge Management* for the valuable revision suggestions to this paper.

1. Introduction

Global economy is converting from recession to recovery at present, and there are a lot of uncertain factors in the complex and varied market environment. This means an unpredictable and high velocity circumstances for the organizations. In these conditions, the possession of valuable, rare, inimitable and non-substitutable resources (Barney, 1991) must not lead to competitive advantage, although by building dynamic capabilities for the company. Dynamic capabilities are the combination of organizational assets to create valuable product or services for customers and it includes three activities of sensing, seizing and transforming knowledge (Teece, 2011; Eisenhardt and Martin, 2000). All of these initiatives are highly dependent on the cooperation and knowledge sharing of organizational member, and the strategies of business or R&D should highly focus on cooperation and hardworking in the organization rather than only on individual's knowledge or intelligence. Undoubtedly, competitiveness of enterprise comes from sustaining and efficient organizational cooperation, and the core essence of organizational cooperation is knowledge cooperation, which means activation, conversion and integration of organizational knowledge resource, it is a necessary premise for an enterprise to implement innovation strategies. Nevertheless, to great extent, it is still an appearance without essential meanings, though knowledge cooperation's role in promoting innovation and performance of organization has been well accepted (Szulanski, 1996; Tsai, 2001; Lee, 2005). According to study of Okhuysen and Eisenhardt (2002), although communication between employees provides the premise and the possibility of knowledge sharing, sharing may not happen exactly as intended and what is shared may be information instead of knowledge, which will not have significant influence on integration of knowledge. Okhuysen's research illustrated the existence of strategic behavior within the knowledge cooperation. In fact, the tacit knowledge transferring could be viewed as the most classic representative of this strategic behavior; nevertheless, tacit knowledge has a crucial influence on the success of innovation processes in companies (Hu and Randel, 2014), but there are many barriers to hinder the sharing of tacit knowledge. For this, it is very necessary to analyze the micro-interactive mechanism of knowledge sharing from perspectives of technology, psychology and institution that will offer a vital theoretical reference for organization to improve the performance of knowledge sharing.

2. Explanation of study methodology

2.1 Enlightenments of literature reviewing

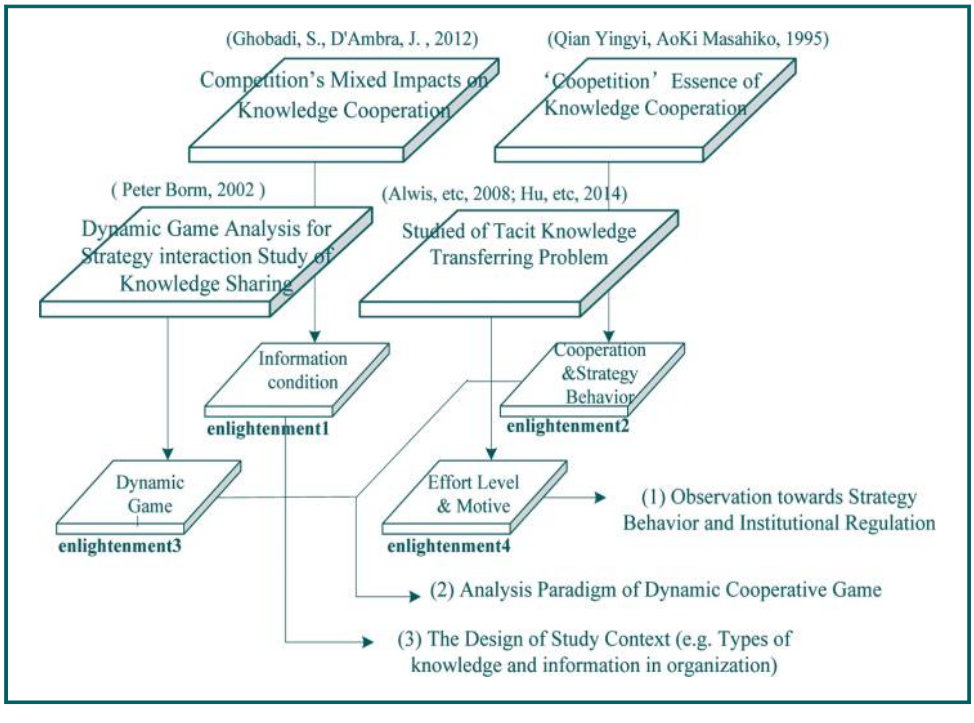
The "coopetition" character of knowledge sharing has been sufficiently demonstrated by Qian Yingyi and AoKi Masahiko's research (Qian and Aoki, 1995), which indicates that there would be common interest among team members during knowledge cooperation, and the game between members would not be a zero sum competition game, but a relationship of cooperation game. To better understand the "coopetition" mechanism of knowledge sharing, Ghobadi and D'Ambra (2012) revealed the competition's mixed impacts on knowledge cooperation in cross-functional teams by building quantitative model that illustrated the intricate interactions between cooperation and competition, e.g. sometimes competition for tangible resources plays a positive role in promoting knowledge cooperation, sometimes competition for intangible resources has negative impact on knowledge cooperation. Above studies imply two key factors: First is knowledge sharing that belongs to the complex "coopetition" problem, which means that there must exist benefit game between individuals in addition to cooperation driven by common objective; therefore, to apply the game theory method is appropriate and effective for knowledge sharing study. Second is the mixed effects of competition on knowledge cooperation (Ghobadi and D'Ambra, 2012), which offers a crucial inspiration that information condition should be a vital analysis dimension and should be absorbed into the design of the study.

Some representative studies also applied game theory to analyze the behaviors or motivation of knowledge sharing, however, study paradigms deviated from the real situation of knowledge sharing at some extent; for example, to view the knowledge sharing between individuals as a repeated game problem will neglect the fact that for organization members, it is mainly a dynamic strategic reaction to decide whether to share knowledge by judging others' willingness or make efforts of knowledge sharing during a particular cooperation, by sensing the organizational support (Borm *et al.*, 2002), and by assessing the loss and gain of own competitiveness maintaining resulted from knowledge transferring, rather than to make decision by evaluating the average revenue after many rounds of dealing. Therefore, in contrast to repeated game method, to adopt the dynamic game analysis would be more rational for strategy interaction study of knowledge sharing.

Tacit knowledge transferring can serve as the most classic representative of the strategic character in knowledge cooperation; although tacit knowledge has a crucial influence on the success of innovation processes in companies (Hu and Randel, 2014), there are many barriers to hinder the sharing of tacit knowledge, so key institutional levers should be identified and applied to facilitate the transferring of tacit knowledge between members (Alwis and Hartmann, 2008). Undoubtedly, whether tacit knowledge can be effectively shared and how to make tacit knowledge explicit will influence company's competitiveness, as tacit knowledge mainly consists of highly personalized and experiential knowledge which is more considered as a strategic capability resource for maintaining the individual competitiveness, so the most essential problem, e.g. whether to transfer and how much the transfer effort to be paid can be profoundly authenticated in studies of tacit knowledge transferring, that enlightens study to take the individual effort level of knowledge sharing as key variable for observing the strategic behavior of individuals' knowledge cooperation.

According to above literature reviewing, some important and valuable enlightenments can be obtained for analyzing the strategy character of knowledge cooperation between individuals, as shown in Figure 1, the choice of analysis paradigm of dynamic cooperative

Figure 1 Existed literatures' enlightenments to study design



game should be closer to the authentic knowledge cooperation practice, and the strategy characteristics and motives should be designed as key study objectives (variable) which could be effectively observed by the equilibrium analysis of game model. Moreover, the construction of knowledge sharing context based on informational condition is very necessary for study because the difference of effort level for knowledge sharing under the function of same institutional constraints or incentives is generally resulted from different information condition.

2.2 Design of study

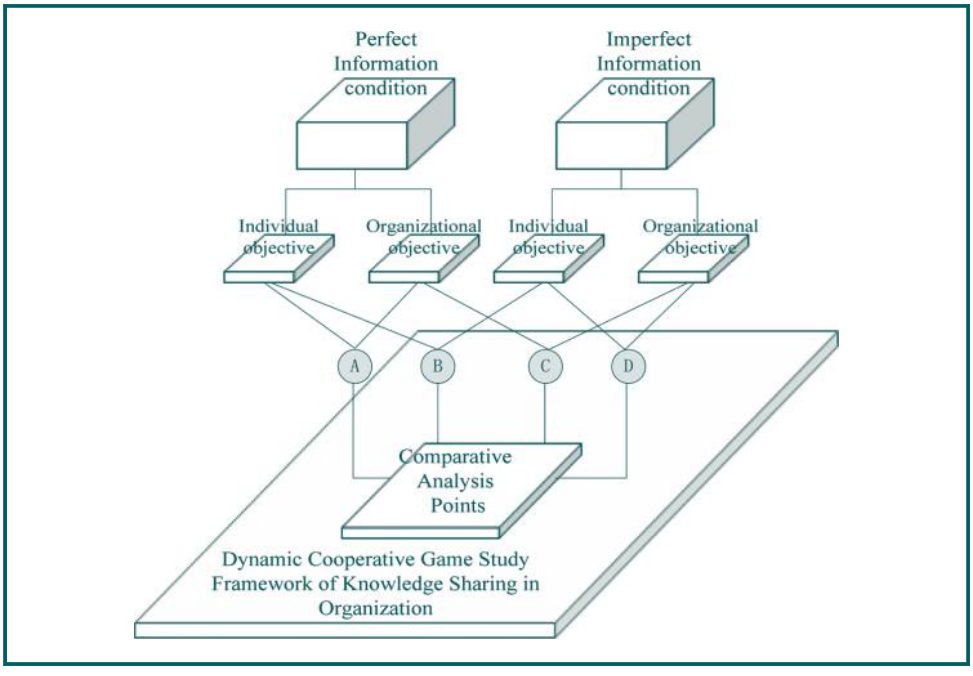
Two key components are vital and prerequisite for constituting the paradigm of this research, one is the study context combining the practical situation where knowledge sharing behavior happens, another one is the objective orientation of individuals' knowledge cooperation combining the psychologic motives of individuals and institutional constraints of organization which will be served as basis of multi-objective function setting. Some representative studies brought many enlightenments for establishing study context and identifying the motivation of knowledge sharing, e.g. Ghobadi and D'ambra (2011) identified two different types of knowledge sharing in literature: one is cooperative type of knowledge sharing being used to reach common interest of partners, another is competitive type of knowledge sharing to stress individual advantages during the knowledge cooperation. Weber (2007) extended further aspects on individual motivation of knowledge sharing with identifying barriers of participants being afraid of becoming a subject of criticism or evaluation or see withholding their knowledge as a way to secure influence. These studies and discoveries help to realize that the motivation of knowledge cooperation should be observed from collective and individual perspectives because almost anyone would balance the interactive effect between self-revenue and collective revenue resulted from knowledge paying and returning; in reality, partners commonly adopt a mixed approach including two different guiding motives, which means it must not be an optimal choice for partners to purely pursue individual revenue or purely pursue collective revenue (Aoki, 2001). Therefore, in this paper, two motives (objectives) function would be established from individual and organizational levels to dissect and explore the incentive mechanism of knowledge sharing.

Paulin (2012) has summarized the influencing factors of effective knowledge sharing from organizational context and motivational factors. Chua (2003) also strengthened the importance of organizational circumstances during the behavior analysis of knowledge sharing. Above studies all stressed on the necessity of building research context of knowledge sharing, although these studies did not concretely describe the composition and structure of context in knowledge sharing owing to the complexity of context problem. As a result, by drawing on previous research, this paper constructs the study context by adopting a method of highly abstractive but closely relating to practical situation, namely, to convert the intricate context factors of knowledge sharing into two classic information conditions:

1. Perfect information condition represents those organizations of working information relatively available and business knowledge relatively conventional.
2. Imperfect information condition represents those organizations of working information relatively intricate and business knowledge highly personalized and implicit.

According to above explanation and demonstration toward the design of this paper, the framework or paradigm of this paper could be illustrated (Figure 2). This study will adopt the comparative analytic method to dissect the micro-mechanism of knowledge sharing from individual and organizational perspectives. The concrete targets of this research are following:

Figure 2 Dynamic cooperative game study framework of knowledge sharing



- to disclose the strategic characteristics and differences during knowledge cooperation between partners (knowledge output of transferor and knowledge returning of receiver) under the same and different information condition;
- to compare the knowledge sharing efficiency and to explain the reason for efficiency difference according to the two-dimensional study context being constituted by two sorts of perspective combination (individual revenue orientation and organizational revenue orientation and perfect information condition and imperfect information);
- to observe the impaction and function on knowledge sharing between individuals from organizational institutional constraints which ensures the behavior of sharing could obtain the return from receiver;
- to demonstrate and exhibit the dynamic and interactive character of knowledge partners during the equilibrium analysis of knowledge sharing under the two-dimensional study context; and
- to dissect the strategic reaction characteristics between two players (knowledge transferor and knowledge receiver) in a given two-dimensional context that would make for the observation and analysis toward the micro-mechanism of knowledge sharing in organization.

This paper firstly constructs a study paradigm relating to a practical situation through establishing the analytical model of dynamic cooperative game, as compared with other studies that started from competitive game perspective that deviates from the essence of knowledge cooperation, or viewed knowledge sharing in organization as a repeated cooperative game problem that is somewhat inconsistent with practice, or studied the individuals' motives through analyzing and categorizing the possible barrier variables, e.g. individual motive, organizational culture and technology barriers (Liu *et al.*, 2016), that fails to form an integrated and systematic analytic framework. The exploration and discovery of Liu *et al.* provides valuable design reference for context construction of knowledge sharing

study. Another methodological contribution of this paper to the subject is that previous studies corresponding to intricate context factors (variables) could be converted into the highly generalized analysis toward information condition (perfect or imperfect) of knowledge sharing, which helps to simplify the building of dynamic cooperative game model, simultaneously without loss of practical, rational, effective and universal sense and also makes the dynamic cooperative game study of knowledge sharing in organization become possible.

3. Dynamic cooperative game model of knowledge sharing

3.1 Explanation for model and variables

In real corporate organization, the process of knowledge sharing between individuals can be understood as a classical dynamic game process. For example, because of organizational or individual interest, Player 1 decides whether to take out a ratio β of his inherent knowledge amount within the organization for sharing and after absorbing or accepting the knowledge output from Player 1, Player 2 must decide whether to share a ratio ρ of his own inherent knowledge in return to Player 1. This problem can be understood as a two-stage dynamic game problem (consideration for study simplification): the two-stage dynamic game structure is close to the core of knowledge sharing within the organization; Player 1 may or may not share their knowledge (usually tacit knowledge or key knowledge) with other members of the organization; Player 2 accepting the knowledge output decides whether to take cooperative strategy to contribute his own knowledge in return. If the answer of Player 2 is "yes", then the process of knowledge sharing can be viewed as a repetition of "Player 1–Player 2" process. If the answer of Player 2 is "no", then the behavior of knowledge sharing between members will be interrupted.

In this cooperative game structure: $S_1(\theta_1)$ is the function of Player 1's ability to use knowledge, θ_1 is assumed to be Player 1's inherent amount of knowledge; $S_2(\theta_2)$ is the function of Player 2's ability to use knowledge, θ_2 is assumed to be Player 1's inherent amount of knowledge; assume Player 1 and Player 2 wish to mutually control the other party's gains when using his own knowledge output $S_1(\rho\theta_2)$, $S_2(\beta\theta_1)$ because that will endanger their competitive advantage within the organization if it's beyond a certain level, so there is a constraint for the gains two sides get when using each other's knowledge output, that is $S_2(\beta\theta_1) + S_1(\rho\theta_2) \leq u_l$, u_l is gain control summation for the parties to use the output of each other's knowledge.

3.2 Explanation for dynamic cooperative game mechanism of knowledge sharing

In actual state of knowledge sharing between the staffs within the enterprise, as Player 1 and Player 2 belong to same organization, so there is a common revenue objective that means it is not a relation of "zero sum game", but a cooperative game of existing the "co-payment". A cooperative game should be understood as forming a unanimous consent agreement between all the players under certain constraints. The selected agreement could meet the common interests of all parties. Cooperation in game theory does not mean that parties sacrifice its own interests for the interests of other parties, every interaction of information or coordinative action is essentially to pursue their own interests.

The mechanism character of dynamic knowledge cooperative game is as follows. First, when Player1's knowledge sharing brings Player 2 gains increment, Player 2 must pay the part of gains increment to return the knowledge output according to the institutional constraint, so the respective knowledge revenue from the interactively transfer between Player1 and Player2 is $\kappa S_1(\rho\theta_2)$, $\kappa S_2(\beta\theta_1)$. k is for the statutory rate of knowledge gains which an organization issues. Second, the implementation of knowledge-exchange strategy for the players is seen as a credible commitment because the organization will constrain the behavior of just using others' knowledge output but refuse to share their knowledge through

effective punishment mechanism. Therefore, the penalty function for Player 1 is $f[S_1(\rho\theta_2)]$; the penalty function for Player 2 is $f[S_2(\beta\theta_1)]$. Third, the organization establishes a target task constraint for Player 1 and Player 2's knowledge output gains, that is $S(\theta_1, \theta_2) \ u_0$, u_0 is a utility constant and S is the knowledge output function for corporate organization; in this case, it is not a simple sum of their ability of knowledge using for Player 1 and Player 2, but it is subject to organizational systems, technology characteristics and other complex factors.

4. Perfect dynamic game's Nash equilibrium analysis

In the research, we first consider the organization staff's knowledge sharing game situation in the context of perfect information. More typical industrial technical characteristics are similar to the enterprise's sales team; in the team, every member's target is mainly to win more market share, the exchange of knowledge between members related to demand information, customer information and marketing methods and strategies. For instance, in a company which applies the conventional technologies, the relevant professional knowledge between Player 1 and Player 2 is usually close to perfect information for each other, for example, whether the other side contributed valuable knowledge or information, whether the other side obtained the revenue by using provided knowledge $S_1(\rho\theta_2)$ and $S_2(\beta\theta_1)$, all the things are clear for each other (see the definition of β and ρ in Section 3.1)

Figure 3 illustrates the dynamic game condition between Player 1 and Player 2, with r_1 and r_2, respectively, representing Player 1 and Player 2's payment after two-stages dynamic game, and $L_1(\beta\theta_1)$ and $L_2(\rho\theta_2)$, respectively, representing the (competitive) advantage loss function incurred by output their own knowledge to each other. Therefore, under the dynamic game's various strategies path Player 1 and Player 2's payments (income) are as follows:

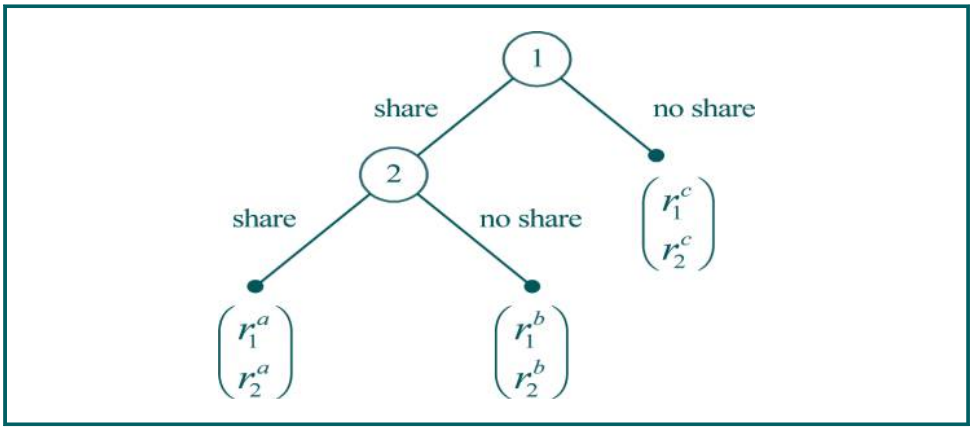
$$r_1^a = S_1(\theta_1) + \kappa S_2(\beta\theta_1) + S_1(\rho\theta_2) - L_1(\beta\theta_1) \tag{1}$$

$$r_2^a = S_2(\theta_2) + (1-\kappa)S_2(\beta\theta_1) - L_2(\rho\theta_2) \tag{2}$$

$$r_1^b = S_1(\theta_1) + \kappa S_2(\beta\theta_1) - L_1(\beta\theta_1) \tag{3}$$

$$r_2^b = S_2(\theta_2) + (1-\kappa)S_2(\beta\theta_1) - f\left[S_2(\beta\theta_1)\right] \tag{4}$$

Figure 3 Perfect dynamic game demonstration of knowledge sharing



$$r_1^c = S_1(\theta_1) \tag{5}$$

$$r_2^c = S_2(\theta_2) \tag{6}$$

Use backward induction to solve the game equilibrium. If they want to make the exchange of knowledge within the organization, Player 2 must choose the cooperative strategy, which is to transfer knowledge and information to the other party after getting the knowledge from Player 1. In this model, Player 2's knowledge regurgitation-feeding behavior is supported by some organized mechanism; see condition (4) in the formula. It is obvious that during the backward induction, both of player1 and player2 are to choose cooperation would be a Nash equilibrium, and the balance pay isr_1^a, r_2^a, then the premise of exchange of knowledge must be $r_2^a \geq r_2^b$, 即 :$fS_2\left[S_2(\beta\theta_1)\right] \geq L_2(\rho\theta_2)$ is the penalty function for Player 2, after absorbing the knowledge output from Player 1, if Player 2 rejected to return knowledge, then he will not be worth the candle because of the punishment mechanism. Penalty function's introduction (third-party mechanism) is considered as one of the key conditions for competitive game transferring to partially cooperative game. For the simplicity of research, this study fix $f[S_2(\beta\theta_1)]$ a specific constant ϖ which is large enough, that means as long as $L_2(\rho\theta_2) \leq \varpi$, then Player 2 (receiving party of knowledge) will select "knowledge sharing" strategy in the second stage, all subsequent discussion will be done in this premise (cooperative game analysis framework).

4.1 Knowledge sharing strategy based on organizational revenue optimum under perfect information

First, considering the efficiency of knowledge sharing between individuals from the view of organizational overall interests, namely, from an organizational perspective, the expected individual member's (the players) intensity of knowledge output, β and ρ are alike. Building an objective function of organization returns from knowledge sharing, we get:

$$\begin{aligned}\max\left(r_1^a + r_2^a\right) = {} & S_1(\theta_1) + \kappa S_2(\beta\theta_1) + S_1(\rho\theta_2) - L_1(\beta\theta_1) \\ & + S_2(\theta_2) + (1-\kappa)S_2(\beta\theta_1) - L_2(\rho\theta_2)\end{aligned} \tag{7}$$

Consider the constraint (8); see part 3.2's note:

$$st. \begin{cases} S(\theta_1, \theta_2) \geq u_0 \\ S_2(\beta\theta_1) + S_1(\rho\theta_2) \leq u_l \end{cases} \tag{8}$$

Build function of Lagrange conditioned extreme value as follows:

$$Lagrange. \begin{bmatrix} S_1(\theta_1) + \kappa S_2(\beta\theta_1) + S_1(\rho\theta_2) - L_1(\beta\theta_1) \\ + S_2(\theta_2) + (1-\kappa)S_2(\beta\theta_1) - L_2(\rho\theta_2) \\ -\lambda_1(S(\theta_1, \theta_2) - u_o) - \lambda_2\left(S_2(\beta\theta_1) + S_1(\rho\theta_2) - u_l\right) \end{bmatrix} \tag{9}$$

So, the first-order conditions of organization returns maximization with the exchange of knowledge between Player 1 and Player 2 are:

$$\begin{aligned}(1-\lambda_2)\frac{\partial S_1(\rho\theta_2)}{\partial\rho} - \frac{\partial L_2(\rho\theta_2)}{\partial\rho} = 0 \\ (1-\lambda_2)\frac{\partial S_2(\beta\theta_1)}{\partial\beta} - \frac{\partial L_1(\beta\theta_1)}{\partial\beta} = 0\end{aligned} \tag{10}$$

According to equation (10), when organization returns maximization from knowledge sharing is viewed as priority objective, the expected players' intensity of knowledge output (knowledge sharing will) must satisfy the following inequality combination [equation (11)]. In

addition, considering to the circumstance of λ comparing with 1, when $0 \leq \lambda_2 \leq 1$ and $0 \leq 1 - \lambda_2 \leq 1$, there must be:

$$\begin{aligned} \frac{\partial S_1(\rho\theta_2)}{\partial \rho} &\geq \frac{\partial L_2(\rho\theta_2)}{\partial \rho} \\ \frac{\partial S_2(\beta\theta_1)}{\partial \beta} &\geq \frac{\partial L_1(\beta\theta_1)}{\partial \beta} \end{aligned} \tag{11}$$

The implied message of inequality combination [equation (11)] is: No matter Player 1 or Player 2, under perfect information environment (similar to the organizational context of a marketing team), they require the speed of their advantages' loss resulted from their own knowledge output (marginal knowledge advantage's losses) should be lower than the knowledge gains increase they bring to the other side (marginal knowledge gains' increase), it embodied players' strategic control of knowledge output to maintain their own competitive position in the organization.

4.2 Knowledge sharing strategy based on individual revenue optimum under perfect information

In the organizational context of perfect information, observing the characteristics of knowledge sharing behavior from the players' individual interests (effort of knowledge output, β and ρ), individual gains objective function of knowledge sharing was constructed.

4.2.1 Player 1's individual gains objective function. [Note: constraints are the same as equation (8)]

$$\max S_1(\theta_1) + \kappa S_2(\beta\theta_1) + S_1(\rho\theta_2) - L_1(\beta\theta_1) \tag{12}$$

Build Player 1's function of Lagrange conditioned extreme value as follows:

$$Lagrange. \begin{bmatrix} S_1(\theta_1) + \kappa S_2(\beta\theta_1) + S_1(\rho\theta_2) - L_1(\beta\theta_1) \\ -\lambda_1(S(\theta_1,\theta_2) - u_o) - \lambda_2\big(S_2(\beta\theta_1) + S_1(\rho\theta_2) - u_l\big) \end{bmatrix} \tag{13}$$

Thus, the first-order condition of Player 1's individual returns maximization from knowledge sharing is:

$$(k - \lambda_2)\frac{\partial S_2(\beta\theta_1)}{\partial \beta} - \frac{\partial L_1(\beta\theta_1)}{\partial \beta} = 0 \tag{14}$$

Comparing equation (14) and equation (10), there are two cases that need to be separately discussed.

First, when $k > \lambda_2$, there must be $(1 - \lambda_2) > (k - \lambda_2)$; it means in the process of knowledge sharing under perfect information context, their own self-interest is taken into consideration. Player 1 takes larger control of knowledge output than the one who is under organization benefits as a priority goal.

Second, when $k \leq \lambda_2$, $\frac{\partial S_2(\beta\theta_1)}{\partial \beta}\frac{\partial L_1(\beta\theta_1)}{\partial \beta}$ take the opposite direction, it means that there is a prerequisite that Player 1 should provide knowledge and information to Player 2; that is while bringing knowledge gains increase to others, their own knowledge advantage growth must be met, which reflects a considerable degree of the feature of "knowledge exchange", either no output, or to provide output and get more benefits. Therefore, we can find, as an organizational constraint mechanism, that the statutory return rate k of knowledge proceeds is significant for inducting Player 1's effort of knowledge output (the first actor of knowledge sharing). If k is smaller, Player 1 will act more conservative in the knowledge output efforts and output conditions.

4.2.2 Player 2's individual gains objective function. Note: constraints are the same as equation (8):

$$\max S_2(\theta_2) + (1-\kappa)S_2(\beta\theta_1) - L_2(\rho\theta_2) \tag{15}$$

Build Player 2's function of the Lagrange conditioned extreme value as follows:

$$Lagrange. \left[\begin{array}{l} S_2(\theta_2) + (1-\kappa)S_2(\beta\theta_1) - L_2(\rho\theta_2) \\ -\lambda_1(S(\theta_1,\theta_2) - u_o) - \lambda_2\left(S_2(\beta\theta_1) + S_1(\rho\theta_2) - u_l\right) \end{array} \right] \tag{16}$$

Thus, the first-order condition of Player 2's individual returns maximization from knowledge sharing is:

$$\frac{\partial S_1(\rho\theta_2)}{\partial\rho} = -\frac{\partial L_2(\rho\theta_2)}{\partial\rho} \tag{17}$$

Equation (17) shows that in a perfect information environment, taking the individual gains from knowledge sharing as a priority target, after getting the knowledge output from Player 1, Player 2 (the following actor in the game) would make conservative efforts to "knowledge return". Compared with the case before equilibrium, Player 2 has a stronger motive to control knowledge output, that is, whether to implement "return of knowledge" depending on whether it could further enhance their competitive advantage of knowledge, which shows strong characteristics of "knowledge exchange" and "knowledge control".

5. Harsanyi transformation of non-perfect dynamic game equilibrium analysis to knowledge sharing

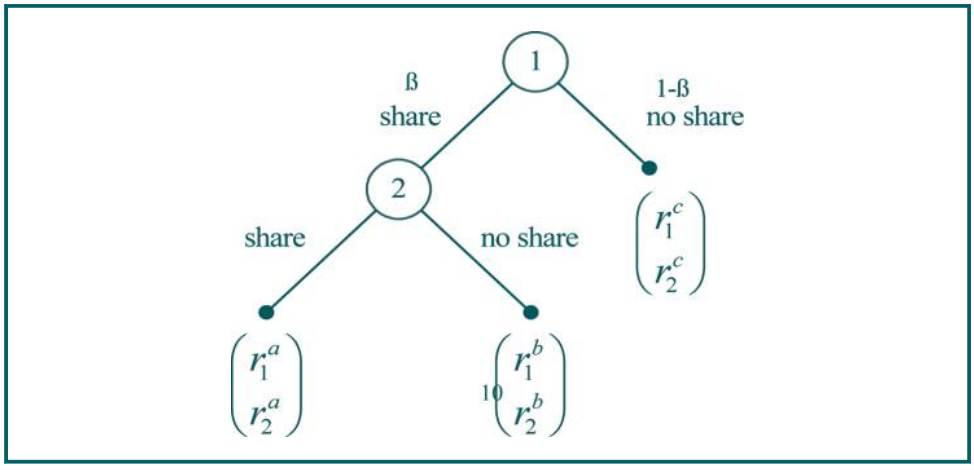
In this paper, another dynamic game context of knowledge sharing is considered, that is imperfect information knowledge sharing mechanism among employees. We can find typical knowledge sharing behavior under imperfect information context, such as accounting firms or the company's R&D centers. For these organizations, although members will exchange knowledge and information among each other under the organizational constraint mechanism, nevertheless, because of the independency of knowledge application and to maintain the competitiveness of individuals, despite cooperation could undoubtedly strengthen the knowledge competitiveness of organizations, the exchange of knowledge among members showed a strong strategic character. Therefore, whether the output of knowledge and information was valuable or the adoption of others' knowledge could gain incremental benefit, is known by the players themselves.

How players determine their own effort of knowledge sharing, in this paper, as shown in Figure 4, is not clear, we can convert this issue to discussion of two probability types of decision-making: "willing" to exchange of knowledge (cooperation) and "unwilling" to knowledge exchange (uncooperative). In fact, it only needs to lock Player 1 (the first actors) with a probability, so that we can observe all players' behavior characteristics under the knowledge sharing mechanism. Here, the probability that Player 1 chooses to cooperate can be equal to Player 1's will of knowledge output β, and the probability to choose non-cooperation is $1-\beta$.

5.1 Knowledge sharing strategy based on organizational revenue optimum under imperfect information

In the context of imperfect information, above all, from the perspective of the organizational overall interests, we consider determinants to the knowledge output intensity β and ρ

Figure 4 Imperfect dynamic game demonstration of knowledge sharing



among individual members. To this end, we build an objective function about the organizational gains of knowledge sharing:

$$\begin{aligned}&\max \beta\left(r_1^a + r_2^a\right) + (1-\beta)\left(r_1^c + r_2^c\right)\\&= \beta S_1(\theta_1) + \beta\kappa S_2(\beta\theta_1) + \beta S_1(\rho\theta_2) - \beta L_1(\beta\theta_1) + \beta S_2(\theta_2)\\&+ \beta(1-\kappa)S_2(\beta\theta_1) - \beta L_2(\rho\theta_2) + (1-\beta)(S_1(\theta_1) + S_2(\theta_2))\end{aligned} \tag{18}$$

Constraint condition is same to equation (8), we construct the Lagrangian extremal function as follows:

$$Lagrange. \begin{bmatrix}\beta S_1(\theta_1) + \beta\kappa S_2(\beta\theta_1) + \beta S_1(\rho\theta_2) - \beta L_1(\beta\theta_1) + \beta S_2(\theta_2)\\+ \beta(1-\kappa)S_2(\beta\theta_1) - \beta L_2(\rho\theta_2) + (1-\beta)(S_1(\theta_1) + S_2(\theta_2))\\- \lambda_1(S(\theta_1,\theta_2) - u_o) - \lambda_2\left(S_2(\beta\theta_1) + S_1(\rho\theta_2) - u_l\right)\end{bmatrix} \tag{19}$$

In non-perfect dynamic game, knowledge exchange among members brings about maximized benefits to the organization, and its first-order conditions are:

For Player 1:

$$\beta^2\left(\frac{\partial S_2(\beta\theta_1)}{\partial\beta} - \frac{\partial L_1(\beta\theta_1)}{\partial\beta}\right) = S_1(\rho\theta_2) - L_2(\rho\theta_2) - \beta\lambda_2\frac{\partial S_2(\beta\theta_1)}{\partial\beta} \tag{20}$$

For Player 2:

$$(\beta - \lambda_2)\frac{\partial S_1(\rho\theta_2)}{\partial\rho} - \frac{\partial L_2(\rho\theta_2)}{\partial\rho} = 0 \tag{21}$$

The following is Player 1's status: compare equation (20) with equation (21), which can be seen as follows: in this knowledge exchange environment with incomplete information such as accounting firm or a technology R&D center, the time that Player 1 (the one firstly implement knowledge sharing) determines the output intensity of his/her own knowledge requires $\frac{\partial S_2(\beta\theta_1)}{\partial\beta} - \frac{\partial L_1(\beta\theta_1)}{\partial\beta} \geq 0$. With respect to Player 1's expectation of knowledge output intensity under perfect information context, the intention under imperfect information would be more conservative; that is, to ensure the competitive advantage, loss of knowledge output is controlled in a certain range. This suggests that in a relatively independent organization environment, which refers to the application of knowledge and technology,

considering the overall interests of the organization, it is very difficult to promote knowledge workers to share proactively.

Player 2's situation: by comparing equation (21) with equation (10), we can find Player 2 as the "follow-actor" of the knowledge exchange, after gaining Player 1's knowledge output. Because $(\beta - \lambda_2) \leq (1 - \lambda_2)$, the effort of Player 2 makes their knowledge return relatively passive. In addition, considering from the perspective of the whole organization, discussing Player 1's intensity of knowledge output β, we can discover that under the imperfect information, Player 2's (after-actor) knowledge sharing behavior is more complex. We discuss two conditions:

1. First, when $\beta > \lambda_2$, Player 2 would rather return their knowledge than that in the case of perfect information. The explanation may be that the percentage β (intensity) of the knowledge Player 1 output is high. This in itself is an effective incentive for players who return their knowledge.
2. Second, when $\beta \leq \lambda_2$, tactics Player 2 adopts are similar to that in the case of perfect information. The "knowledge return" implemented depends on the possibility that further enhances the competitive advantage of their knowledge that means player 2 also displays stronger psychological characteristic of self compensation and self correction, and the reason is possibly the insufficient effort from player 1's knowledge sharing leads Player 2 to take a more cautious approach to return knowledge.

5.2 Knowledge sharing strategy based on individual revenue optimum under imperfect information

Now we consider the knowledge sharing behavior when individual gains are maximum under imperfect information, which brings the intensity of knowledge output β and ρ. With this in mind, we separately construct Lagrangian conditional extremal value function [equation (22) and (23)], which makes Players 1 and 2's individual benefits maximum, constraints with equation (8):

$$Lagrange. \begin{bmatrix} \beta S_1(\theta_1) + \beta\kappa S_2(\beta\theta_1) + \beta S_1(\rho\theta_2) - \beta L_1(\beta\theta_1) + (1-\beta)S_1(\theta_1) \\ -\lambda_1(S(\theta_1,\theta_2) - u_o) - \lambda_2\big(S_2(\beta\theta_1) + S_1(\rho\theta_2) - u_l\big) \end{bmatrix} \tag{22}$$

$$Lagrange. \begin{bmatrix} \beta S_2(\theta_2) + \beta(1-\kappa)S_2(\beta\theta_1) - \beta L_2(\rho\theta_2) + (1-\beta)S_2(\theta_2) \\ -\lambda_1(S_1(\theta_1) + S_2(\theta_2) - u_o) - \lambda_2\big(S_2(\beta\theta_1) + S_1(\rho\theta_2) - u_l\big) \end{bmatrix} \tag{23}$$

According to the above equations, we can export the first-order conditions: Players 1 and 2's personal best efforts in knowledge sharing:

For Player 1:

$$\beta^2\left(k\frac{\partial S_2(\beta\theta_1)}{\partial\beta} - \frac{\partial L_1(\beta\theta_1)}{\partial\beta}\right) = S_1(\rho\theta_2) - \lambda_2\beta\frac{\partial S_2(\beta\theta_1)}{\partial\beta} \tag{24}$$

For Player 2:

$$-\beta\frac{\partial L_2(\rho\theta_2)}{\partial\rho} - \lambda_2\frac{\partial S_1(\rho\theta_2)}{\partial\rho} = 0 \tag{25}$$

Comparing between equation (24) and equation (20), it's clear that from maximizing their own interests, as opposed to perfect information context, under imperfect information, the

knowledge output willingness of Player 1 is more stringent and the control degree of knowledge outputting is enhanced, which requires the gap between the marginal revenue $\frac{\partial S_2(\beta\theta_1)}{\partial\beta}$ of others from own knowledge outputting and the marginal competitiveness loss $\frac{\partial L_1(\beta\theta_1)}{\partial\beta}$ of own from knowledge outputting enough big. In addition, by comparing equation (25), (17) and (21), it could be found that the strategy of Player 2's knowledge outputting is similar to the strategy of maximizing personal gains under the perfect information and maximizing organizational benefits under imperfect information, which means when the goal is to maximize the individual benefit of knowledge-sharing, but not until the knowledge output can bring more knowledge advantage, Player 2 as the follow-actor is willing to exchange knowledge with Player 1.

Overall, in the context of imperfect information, Player 2 as the follow-actor during knowledge-sharing dynamic cooperative games, their effort of the "knowledge return" tends toward more conservative approach and exhibits strong "knowledge transaction" characteristics.

6. Conclusions

6.1 Research discoveries

Knowledge sharing mechanism within the organization is essentially a typical problem of dynamic cooperative game. Not only the organization's institutional constraints or incentives, the common interests among members which produced from the cooperative efforts, but also the intention which members maintain their competitiveness within the organization: to maximize their own gain from production of knowledge resulting from acts of each strategy, all of these cause mutual strategic action among players. The results indicate that the process of dynamic knowledge sharing game and the players at any stage of the knowledge sharing efforts are based on the premise of the interests of specific targets, and the intensity to knowledge contribution is up to the completeness of information and the effectiveness of institutional regulation in organizational context. The study findings to the dynamic strategic characteristics of knowledge sharing in organization have been specifically summarized in Table I, and the main research conclusion is as follows:

On the perfect information condition, because organization members' action strategy and strategic income could be easily observed in the circumstance of working information relatively transparent and business knowledge relatively conventional, members would strategically control the intensity of their knowledge output. Although the existence of punishment and incentive mechanism is able to ensure the continued sharing of organizational knowledge, the prerequisite of the knowledge receiver's effort to return their knowledge is to get more competitive advantage in knowledge exchange, that appears as an obvious "knowledge transaction" characteristic.

In contrast to perfect information context, under the context of working information relatively intricate and business knowledge highly personalized and implicit where members' behavior and strategic income could be not easily observed, either for organizational objective orientation or for individual orientation, knowledge transferor and knowledge receivers would appear more conservative and more stringent for knowledge outputting. It is worth noting that under imperfect information condition, the return effort of knowledge receiver is adjusted flexibly according to the amount and value of knowledge from transferor in the first stage, and no matter from which angle, proceeds optimum for organization or individual, knowledge return within the organization appears a higher "knowledge transaction" characteristics.

Since members of organization consider the combination of implementing the institutional requirements and pursuing individual competitiveness during the

Table I Description of dynamic strategy characteristic of knowledge sharing

Perfect information condition		
Organizational objective orientation	Strategy character of transferor	The loss velocity caused by knowledge output would be less than the knowledge revenue increasing of receiver who receives knowledge sharing
	Strategy character of receiver	The loss velocity caused by knowledge returning had better be less than the knowledge revenue increasing of transferor who receives knowledge sharing
Individual objective orientation	Strategy character of transferor	The control degree of loss velocity in knowledge output is higher than the circumstance of organization objective priority. The motivation level of knowledge sharing of transferor depends on statutory return rate *k* of knowledge proceeds
	Strategy character of receiver	The knowledge return effort of receiver is generally conservative, and the return effort depends on whether the knowledge from transferor could strengthen receiver competitiveness
Imperfect information condition		
Organizational objective orientation	Strategy character of transferor	Knowledge output would be controlled in a certain and safe range, the share effort or willingness is more conservative than under perfect information condition
	Strategy character of receiver	Knowledge return behavior of receiver appears knowledge transaction character, the return effort would increase if knowledge sharing from transferor could bring about the increasing of competitiveness, otherwise the return effort would be reduced
Individual objective orientation	Strategy character of transferor	The loss velocity of knowledge sharing would be much slower than receiver's knowledge revenue increasing, and there had better be a enough (safe) distance between loss velocity and increasing velocity that appears dynamic strategic character
	Strategy character of receiver	Neither any change for loss velocity of knowledge return nor for advantage increasing velocity of transferor who obtains knowledge return that would be the optimal strategy for receiver. Generally, the opinion of receiver's knowledge return is more conservative and appears stronger "self-correction" character

knowledge cooperation process, so members' strategic choice owns highly mixed and contingent character, and simultaneously there tends to be the background function from organizational circumstance on knowledge sharing that could be found in Table I; for example, the penalty constraint and incentive mechanism (statutory rate *k*) could play an effective role in regulating or prompting the knowledge sharing under perfect information condition, irrespective of organization orientation or individual orientation, and irrespective of whether the player is a knowledge transferor or receiver. However, statutory rate seems to have little effect on the promotion of knowledge sharing under the imperfect information condition irrespective of any dimension, because members of knowledge-intensive organization or institutes where techs information is more intricate, professional knowledge is highly personalized and implicit, are more sensitive to knowledge competitiveness, so which knowledge is to be shared and how much the effort should be made will depend on their own practical observation of their partners' reaction and the dynamic assessment on the value of knowledge sharing (returning).

The results of equilibrium analysis to knowledge sharing strategy from organizational objective perspective should be viewed as a start point (baseline) of incentive design that could maintain the basic sharing level produced by individual efforts because of the driving of institutional constraints and incentive, while the motivation of knowledge sharing from individual perspective should be relatively emphasized by institution design or study, because to consist the incentive compatibility mechanism considering individual and organizational objectives is critical and basic for encouraging and enhancing the knowledge sharing effort of individuals.

6.2 Practical value and sense

The practical value and sense of this paper brought by this study with two dimensions (objective orientation and information condition) related to each other, is that especially for those high techs companies, the driving from institutional constraints

and incentive would ensures the formal existence of knowledge sharing that could not essentially influence the efficiency of knowledge sharing in organization. For instance, although transferor knows he would obtain the so called knowledge return at the statutory return rate *k* for his knowledge contributing, but he could not know the actual value of these knowledge for maintaining or improving his competitive edge, while receiver has indeed accomplished the knowledge return at statutory rate *k*. Vice versa, if above interaction process is observed in a dynamic perspective, the receiver's consideration and worries to value of knowledge sharing, which means the only sure result about institutional constraints is the behavior of knowledge sharing rather than performance. Therefore, to stimulate and encourage the individuals' willing and effort of knowledge sharing from property institution design, or to innovate the structure of governance and management is more effectual through drawing on some effective and advanced thoughts of successful enterprises, e.g. to establish the business partner institution and relevant cooperative culture which is vastly popularized in prompting the action of innovation and entrepreneurship in China at present, and some matched institution designs, such as ESOP, follow investor, the flattening of management structure which emphasizes decentralization and so on, could convert staffs from former factors of production to owners of enterprises, that would fundamentally stimulate the individual willing of knowledge sharing.

6.3 Research limitation

Although the study combining the cooperative essence and dynamic game is first adopted to analyze the individual strategic characteristics during knowledge sharing in this paper, and a multi-study context composition of two different perspectives (objective orientation and information condition) is correspondingly constructed to be in accordance with the practical circumstance of knowledge action in organization, the design of game structure failed to consider the hierarchy problem, namely, there is also a team objective orientation between individual and organizational objective orientations. As the accomplishment of organizational objectives mainly depends on the task implementing and the coordination of departments or projects (teams), and as the motivation orientation of individuals, team leaders and organization differentiates each other, so it would be more authentic to construct the study paradigm including multi-hierarchy structural function to demonstrate the complexity of interactive strategic behavior of knowledge sharing, and there is also a team objective orientation between individual and organizational objective orientations because the accomplishment of organizational objectives mainly depends on the task implementing and the coordination of departments or projects (teams), and because the motivation orientation of individuals, team leaders and organization differentiates each other, the empirical discovery of the knowledge sharing performance is subject to who would be rewarded (individuals, team or organization) undoubtedly provided this study much inspiration. Moreover, the effects of social capital on knowledge sharing should be considered for perfecting the dynamic cooperation game model, because social capital is considered as the facilitator of knowledge searching and knowledge sharing, which is very vital to innovation performance (Alguezaui and Filieri, 2010), so in the connotation of social capital there naturally involves the complex considerations of relationship (networks), values, beliefs, regulation, etc. that will make individuals dynamically and flexibly mediate strategic choice of knowledge sharing. Above research limitation would become future effort direction of this study, after all the method of multi-context dynamic cooperative game and relevant discoveries of this paper has formed an effectual and substantial study basis for future challenge.

References

Alguezaui, S. and Filieri, R. (2010), "Investigating the role of social capital in innovation: sparse versus dense network", *Journal of Knowledge Management*, Vol. 14 No. 6, pp. 891-909.

Alwis, R.S.D. and Hartmann, E. (2008), "The use of tacit knowledge within innovative companies: knowledge management in innovative enterprises", *Journal of Knowledge Management*, Vol. 12 No. 1, pp. 133-147.

Aoki, M. (2001), *Toward Comparative Institutional Analysis*, Shanghai Far East Press, Shanghai, pp. 315-317.

Barney, J. (1991), "Firm resources and sustained competitive advantage", *Journal of Management*, Vol. 17 No. 1, pp. 99-120.

Chua, A. (2003), "Knowledge sharing: a game people play", *Aslib Proceedings*, Vol. 55 No. 3, pp. 117-129.

Eisenhardt, K.M. and Martin, J.A. (2000), "Dynamic capabilities: what are they?", *Strategic Management Journal*, Vol. 21 Nos 10/11, pp. 1105-1121.

Ghobadi, S. and D'Ambra, J. (2011), "Coopetitive knowledge sharing: an analytical review of literature", *The Electronic Journal of Knowledge Management*, Vol. 9 No. 4, pp. 307-317.

Ghobadi, S. and D'Ambra, J. (2012), "Knowledge sharing in cross-functional teams: a coopetitive model", *Journal of Knowledge Management*, Vol. 16 No. 2, pp. 285-301.

Hu, L. and Randel, A.E. (2014), *Knowledge Sharing in Teams: Social Capital, Extrinsic Incentives, and Team Innovation*, Group & Organization Management.

Lee, J.N. (2005), "The impact of knowledge sharing, organizational capability and empirical application", *Strategic Management Journal*, Vol. 26, pp. 277-285.

Liu, L., Rong, D. and Zhong, A. (2016), "Influence of culture on relationship between knowledge sharing and innovative behavior in service enterprises", *China Management Science*, No. 4, pp. 57-63.

Paulin, D. (2012), "Barriers – three blurry terms in KM", *The Electronic Journal of Knowledge Management*, Vol. 10 No. 1, pp. 81-91.

Okhuysen, G.A. and Eisenhardt, K.M. (2002), "Integrating knowledge in groups: how formal interventions enable flexibility", *Organization Science*, Vol. 13 No. 4, pp. 370-386.

Qian, Y. and Aoki, M. (1995), *Company Governance Structure under Economy Transform*, 1st ed., China Economy Press.

Szulanski, G. (1996), "Exploring internal stickiness: impediments to the transfer of best practice within the firm", *Strategic Management Journal*, Vol. 17 No. S2, pp. 27-44.

Teece, D.J. (2011), "Dynamic capabilities: a guide for managers", *IVEY Business Journal*, (March/April 2011), p. 5.

Tsai, W. (2001), "Knowledge transfer in intra organizational networks: effects of network position and absorptive capacity on business unit innovation and performance", *Academy of Management Journal*, Vol. 44 No. 5, pp. 996-1004.

Weber, R. (2007), "Knowledge management in call centres", *The Electronic Journal of Knowledge Management*, Vol. 5 No. 3, pp. 333-334.

Further reading

Aoki, M. (2005), *The Co-operative Game Theory of Firm*, 1st ed., China People University Press, Beijing, pp. 2-6.

Becker, T.E. (2006), "Foci and base of commitment: are they distinctions worth making", *British Journal of Management*, No. 19, pp. 337-357.

Borm, P., Estevez-Fernandez, A., and Fiestras-Janeiro, M.G. (2005), "Competitive environments and protective behaviour," Discussion Paper 50, Tilburg University, Center for Economic Research.

Coase, R. (1937), "The nature of the firm, economican. s: 4386-405", in Stigler, G.J. and Boulding, K.E. (Eds), *Reading in Price Theory*, pp. 331-551.

Cummings, J.L. and Teng, B. (2006), "The keys to successful knowledge-sharing", *Journal of General Management*, Vol. 31 No. 4, pp. 1-18.

Hansen, M.T. and Haas, M. (2008), "Different knowledge, different ben-efits: toward a productivity perspective on knowledge sharing in organizations", *Strategic Management Journal*, Vol. 1 No. 11, pp. 1133-1153.

He, H. and Jisheng, P. (2009), "Research among relationship between perceived organizational support, the ways of knowledge sharing behavior and sharing effectiveness", *SCIENCE OF SCIENCE AND MANAGEMENT OF S.&.T*, Vol. 30 No. 11, pp. 52-58.

Bilbao, J.M. (2000), *Cooperative Games on Combinatorial Structures*, Kluwer Academic Publishers, The Netherlands.

Bilbao, J.M., Edelman, P.H., Bilbao, J.M. and Edelman, P.H. (2000), "The Shapley value on convex geometries", *Discrete Applied Mathematics*, Vol. 103 Nos 1/3, pp. 33-40.

Levin, D. and Cross, R. (2004), "The strength of weak ties you can trust: the mediating role of trust in effective knowledge transfer", *Management Science*, Vol. 50 No. 11, pp. 1477-1490.

Liao, S.H., Chang, J.C., Cheng, S.C. and Kuo, C.M. (2004), "Employee relationship and knowledge sharing: a case study of a. Taiwanese finance and securities firm", *Knowledge Management. Research & Practice*, Vol. 2 No. 1, pp. 24-34.

Nonaka, I. and Hirotaka, T. (1995), *The knowledge creating company: how Japanese companies create the dynamics of innovation*, Oxford University Press, New York, NY, p. 284.

Tsai, W. (2002), "Social structure of "competition" within amultiunit organization: coordination, competition, and intra organizational knowledge sharing", *Organization Science*, Vol. 13 No. 2, pp. 179-190.

Tsui, A.S., Pearce, J.L., Porter, L.W. and Tripoli, A.M. (1997), "Alternative approaches to the employee-organization relationship: does investment in employees pay off? ", *Academy of Management Journal*, Vol. 40 No. 5, pp. 1089-1121.

Van Alystine, M.W. (2005), "Create colleagues, not competitors", *Harvard Business Review*, Vol. 83 No. 9, pp. 24-28.

Wang, S. and Noe, R.A. (2010), "Knowledge sharing: a review and directions for future research", *Human Resource Management Review*, Vol. 20, pp. 115-131.

Wu, Q. and Zhang, W. (2016), "Incentive selection strategy for large-scale knowledge sharing", *Journal of Systems Management*, No. 3, pp. 499-505.

Yu, M. (2011), "Study on relationship between individualism/collectivism tendency and knowledge sharing intention: the moderating role of knowledge activity", *Nankai Management Review*, No. 6, pp. 78-85.

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