KNOWLEDGE SHARING OF SENIOR EMPLOYEES IN THE CONTEXT OF TASK-BASED COOPERATION: A GAME THEORETIC ANALYSIS

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Abstract

The aging of population has become a global trend and the critical knowledge of enterprises may be lost with the retirement of senior employees. Task-based cooperation is an important method to prevent the loss of knowledge and to promote the knowledge sharing behavior between senior employees and young ones. This paper constructs the knowledge contribution payoff functions of senior employees and young ones in the context of task-based cooperation and analyzes the knowledge contribution behavior using static game theory with complete information, and then we obtain Nash equilibrium solutions under different conditions. The results suggest that enterprises can promote knowledge contribution of senior employees and young ones in the process of task-based cooperation by improving social rate of return (e.g., creating a good cultural atmosphere), reducing cost rate of knowledge contribution (e.g., training on knowledge expression), raising economic rate of return and providing monetary compensation according to the contribution of knowledge, whether the marginal payoff of employees’ knowledge contribution is increasing, invariant or diminishing. Since the formation of social return is difficult in the short term, giving economic incentives can be an effective way at the beginning. With the progress of task-based cooperation between senior employees and young ones, the amount of employees’ knowledge (especially of young ones’), the productivity of knowledge contribution, the collaborative efficiency and social rate of return will increase and therefore economic incentives contributing to cooperation between both players may decrease appropriately. The findings of this paper are beneficial to understand knowledge sharing behavior in the context of task-based cooperation, and provide several incentive mechanisms for enterprises to promote knowledge sharing between senior employees and young ones.

Keywords: Senior employees, Task-based cooperation, Knowledge sharing, Game, Incentive mechanism
INTRODUCTION

Under the background of knowledge economy, knowledge has become the most important element of corporate strategy (Spender 1996), which has close relationship with the ability of enterprises to gain competitive advantage (Teece 2001). Since the world has entered the aging society, a growing number of senior employees are entering the retirement age, which will bring significant challenges to the management and application of corporate knowledge assets (Noethen 2011). As the critical tacit knowledge resides foremost in individual employees (Nonaka 1994), the key knowledge of enterprise may lose with the retirement of senior employees, which will result in the weakening of the core competitiveness of enterprises (DeLong 2004; Nunes et al 2006).

Previous studies have shown that knowledge-sharing activities can promote knowledge transfer from senior employees to organizations (Hewitt 2008; Markkula 2013; Noethen 2011). The senior employees are employees near retirement or re-employed after retirement, usually between 55-65 years of age. Since explicit knowledge is easy to transfer, the losing knowledge with the retirement of employees is mainly tacit knowledge unreserved by enterprises, such as the knowledge of know-how, best practice (Thilmay 2008), informal network relationship (McQuade et al. 2007), experience, culture (Hewitt 2008) and so on. Tacit knowledge is difficult to be shared and transferred (Joe et al 2013), so business mentoring (Gray 2011; McQuade 2007), communities of practice (Elkington 2013) are effective ways to acquire tacit knowledge from senior employees. Arranging senior employees and young employees to build a project team and pairing a senior employee with a young one to accomplish a certain task is an effective short-term solution to share tacit knowledge of senior employees. An important issue in this senior-to-young task-based cooperation pattern for knowledge sharing purpose is how to improve the knowledge contribution effort. That means senior employees will contribute knowledge without or with little reservation in cooperation, so that young employees can learn knowledge from senior ones and apply it to practice in a timely manner.

There are many scholars who have studied the general factors affecting knowledge sharing or knowledge transfer between employees (Javadi et al. 2013; Cruz et al 2009; Szulanski 1996 etc.) as well as the affecting factors of knowledge sharing of senior employees (Appelbaum 2012; Noethen 2011; Delong 2004). There are also a lot of studies on knowledge sharing behavior using game theoretic analysis (Li et al 2010; Samieh 2007 etc.). However, little research has been going on either implementing knowledge sharing of senior employees by means of task-based cooperation, or improving knowledge contribution effort under the context of task-based cooperation using game theoretic analysis.

In order to promote senior employees to share their critical knowledge, companies often pair senior employees with young ones to accomplish tasks. This paper addresses the following questions:

- Are there equilibrium solutions of knowledge contribution effort of both senior employees and young ones while maximizing the payoff in the task-based cooperation process? If so, what are the affecting factors?
- What effective incentive mechanisms should be designed by the human resource department of enterprises to improve the knowledge contribution effort of senior employees in the task-based cooperation process?

The paper is organized as follows. In section 2 we review studies on knowledge sharing game and task-based cooperation game. In section 3 we propose the game model with some assumptions. Section 4 analyzes the knowledge sharing behavior between two players as a static game with complete information in the context of increasing, invariant or diminishing marginal payoff, and gains some propositions. In section 5 we design some incentive mechanisms according to the Nash equilibrium solutions under different conditions. In section 6 we make some discussion of our results, and we conclude in section 7.

LITERATURE REVIEW

Currently, there are many studies on knowledge sharing behavior between employees using game theory. Cabrera et al. (2002) regard the information exchange between co-workers in organizations as a co-operation dilemma, and provide some indications that could help organizations increase overall
knowledge sharing. The interventions include those aimed at adjusting the reward for sharing, those that try to improve efficacy perceptions and those that make employees’ sense of group identity and personal responsibility more salient. Lin et al. (2005) propose a game theoretic model to predict the adverse effects on knowledge transfer from incomplete information and information asymmetry, and come up with solutions to mitigate these negative effects. Samieh (2007) points out that knowledge sharing within groups can be seen as a multiplayer game model. Li et al. (2010) analyze the multiplayer game situation of knowledge sharing in communities of practice and propose that IT investment and appropriate incentives can improve knowledge sharing revenue. Zhang et al. (2010) develop a game-theory model to explain knowledge-sharing behavior in knowledge-management system (KMS) and suggest that organizations not only add rewards to promote knowledge sharing between employees but also apply some additional mechanisms, such as a quality-evaluating system, extended information technology support and organizational policy. Sharma et al. (2013) study knowledge flows within organizational eco-systems from the perspective of game theory by generating five commonly occurring scenarios in organizations and analyzing the optimal strategy for each scenario. Previous studies have focused on the general game theoretic analysis of knowledge sharing among employees, and most of the studies haven’t distinguished types of components of the benefit and cost for both players, which is not conducive to subdividing types of motivations and obstacles that affect knowledge sharing, and is difficult to design targeted incentives.

With the development of research, other theoretic frameworks such as social exchange theory, economic exchange theory, motivational crowding-out theory, social cognitive theory are gradually applied to knowledge sharing game. Scholars have focused on the factors such as various motivations, socio-psychology and culture in deriving the perceived payoffs for the involved players (Ghobadi et al. 2011). Gächteret et al. (2010) use game theory to predict knowledge sharing behavior in open source software development context, the results of which show that knowledge sharing is a coordination game with multiple equilibriums and is not only affected by material incentives, but also by social preferences such as fairness. Chua (2003) examines the dynamics of knowledge sharing using the multi-person game-theoretic framework, and decomposes the interests into expected rewards, expected associations and expected contribution. These incentives refer respectively to extrinsic ones. Based on organizational knowledge structure, Chen et al. (2009) analyze knowledge sharing using game theory, and regard knowledge sharing as a behavior of society exchange, whose benefits include not only material benefits but also higher level requirement like feeling, self-pride and self-realization. Previous studies suggest that the payoff of knowledge sharing includes not only economic part but also social part. Accordingly, this paper establishes the senior and young employee’s payoff functions of knowledge contribution in the context of task-based cooperation based on this view.

The literature on the task-based cooperation game is also related with our work. Bandyopadhyay et al. (2007) study the knowledge sharing cooperation problem of “host” firm and outsourcing firm who have to share their knowledge and skill sets in order to work effectively as a team, but might be naturally antagonistic towards each other. Their study shows that when the degree of complementarity of knowledge between the employees is high enough, better payoffs can be achieved if the top management enforces cooperation between the employees of both sides. Zhang (2010) focuses on knowledge-exchange process in the task-based cooperation as games among selfish agents. Each agent exchanges its knowledge with others in order to improve its own ability. Takai(2010) analyzes collaboration problem in engineering design using game theory and defines collaboration conditions when two engineers with diverse technical backgrounds collaborate on a design project in order to maximize product performance with prisoner’s dilemma framework. Cai et al. (2009) use evolutionary game theory to study the discrete-strategy e-collaboration games, by supposing the benefit and cost of both players as a quadratic function of resources invested in collaboration and analyzing how social punishments affecting equilibrium solutions. In this paper, we refer the discrete-strategy e-collaboration game model proposed by Cai et al. (2009) and establish knowledge sharing game model in the process of task-based cooperation between senior employees and young ones, which is used for the analysis of knowledge sharing behavior of both players.
3 MODEL AND ASSUMPTIONS

3.1 Players

In this paper, we consider a two-person cooperation game, assuming that the senior employee as player 1 and the young employee as player 2 are both rational.

3.2 Behavior Strategies

Assuming a scenario of a continuous-strategy game in which players have three choices: complete defection, complete cooperation and partial cooperation that means anywhere between complete cooperation and complete defection. We regard players’ knowledge contribution effort (mainly refers to the proportion of their total knowledge that players are willing and making efforts to contribute) in the task-based cooperation as their strategies. Thus the actual knowledge contribution is the product of knowledge contribution effort and total knowledge. Assumptions below describe the signs of knowledge contribution effort (KCE), total knowledge (TK) and actual knowledge contribution (AKC) of the senior employee and the young one in the task-based cooperation.

A1. The KCE of player 1 is \( p \) while that of player 2 is \( q \) (\( 0 \leq p \leq 1, 0 \leq q \leq 1 \)).

A2. The TK of player 1 is \( K_1 \) while that of player 2 is \( K_2 (K_1 > > K_2 > 0) \).

A3. The AKC of player 1 is \( pK_1 \) while that of player 2 is \( qK_2 \).

3.3 Benefit Function

Social exchange theory suggests that continued benefit is the drive force of individual behavior and interaction. Only when the exchange relationship is attractive will an individual interact actively with others. Findings by Blau (1964) show that besides material exchange, individuals will do non-material resources exchange in social life. In this paper, we consider that the task-based cooperation between player 1 and player 2 is an exchange behavior, in which there is not only material exchange but also non-material exchange. Therefore, both players will obtain economic return (such as money and goods that paid according to the task output) as well as social return (such as social approval, respect, love and gratitude).

(1) Economic Return Function

With the era of knowledge-based economy, knowledge has become an important factor of production. Economists analyze the impact that knowledge, a factor of production, has on economic growth, and suggest that the original law of diminishing marginal product has changed because of knowledge investment, making marginal product increasing in high-tech or knowledge-intensive industries (Griliches 1998; Arrow 1962 etc.) According to the law of increasing marginal product of knowledge, we can consider that in the context of task-based cooperation, the task output is a nonlinear increasing function of knowledge contribution of both players, in which marginal product is increasing. To simplify the analysis, we assume that the task output function of knowledge sharing is a quadratic function. Here are the two specific assumptions.

A4. Player 1’s output function is \( Q_1 = a_1(pK_1)^2 + b_1 pK_1 \) (\( a_1 \) and \( b_1 \) affect the productivity of knowledge contribution (PKC) of player 1, and \( a_1 \geq 0, b_1 \geq 0 \)).

A5. Player 2’s output function is \( Q_2 = a_2(qK_2)^2 + b_2 qK_2 \) (\( a_2 \) and \( b_2 \) affect the PKC of player 2, and \( a_2 \geq 0, b_2 \geq 0 \)).

In addition to the individual output, there is also collaborative output on account of cooperation, which is a function of both players’ knowledge contribution. Therefore, we propose that:

A6. The collaborative output is a correlated item \( \lambda p q K_1 K_2 \) (\( \lambda \) is collaborative efficiency (CE) and \( \lambda > 0 \)) by reference to Cai et al. (2009).
In summary, the total output in cooperation is given by \( Q = Q_1 + Q_2 + \lambda pqK_1K_2 \). As enterprises will pay employees according to the total output, we propose that:

**A7.** Player 1’s economic return can be expressed as

\[
F_1(p) = x_1(a(pK_1)^2 + b_1pK_1 + a_2(qK_2)^2 + b_2qK_2 + \lambda pqK_1K_2) \quad (x_1 \text{ is the economic rate of return (ERR) of player 1, and } x_1 \geq 0).
\]

**A8.** Player 2’s economic return can be expressed as

\[
F_2(q) = x_2[a(pK_1)^2 + b_1pK_1 + a_2(qK_2)^2 + b_2qK_2 + \lambda pqK_1K_2] \quad (x_2 \text{ is the ERR of player 2, and } x_2 \geq 0).
\]

(2) Social Return Function

In the process of task-based cooperation, both of players will obtain not only economic return but also social return because of knowledge contribution. Assuming that social return can be described as a linear function of knowledge contribution, we can propose that:

**A9.** The social return function of player 1 and player 2 can be respectively written as \( s_1pK_1 \) and \( s_2qK_2 \) (\( s_1 \) refers to the social rate of return (SRR) of player 1, and \( s_2 \) refers to that of player 2).

### 3.4 Cost Function

Employees cannot complete the task at once in the process of task-based cooperation, but resolve problems by investing knowledge gradually since different issues should be dealt with by different types of knowledge. Generally, individuals will always give priority to tractable problems with knowledge of easy availability and application (e.g., procedural knowledge). As individuals are getting familiar with tasks, they are required to have a comprehensive analysis of their knowledge and think about how to use it in practice. Besides operation knowledge, knowledge about knowing how to apply knowledge to complete task and intuitive knowledge about solving problems accumulated in the long-term is also necessary but requires more cost. Moreover, individuals need to pay much more if they intend to gain higher level of knowledge and capability as knowledge accumulated to some extent. For instance, it costs more if someone wants to improve his math grades from 80 to 90 (out of 100 points) than that from 60 to 70. Based on the above discussion, we assume that task cost is a nonlinear increasing function of knowledge contribution with increasing marginal cost. To simplify the analysis, the cost of knowledge contribution can be described as a quadratic function. Therefore we propose that:

**A10.** Player 1’s cost function is

\[
C_1 = c_1(pK_1)^2 + d_1pK_1 \quad (c_1, d_1 \text{ affect the cost rate of knowledge contribution (CRKC) of player 1, } c_1 \geq 0, d_1 \geq 0),
\]

Player 2’s cost function is

\[
C_2 = c_2(qK_2)^2 + d_2qK_2 \quad (c_2, d_2 \text{ affect the CRKC of player 2, } c_2 \geq 0, d_2 \geq 0).
\]

### 3.5 Payoff Function

According to the formula of payoff (Payoff = Benefit - Cost = Economic Return + Social Return - Cost), we can write the payoff functions as follows.

**A11.** Player 1’s payoff function:

\[
\pi_1(p) = F_1(p) + s_1pK_1 - C_1
\]

\[
= K_1^2(x_1a_1 - c_1)p^2 + K_1(x_1b_1 + x_1\lambda qK_2 + s_1 - d_1)p + x_1[a_2(qK_2)^2 + b_2qK_2] \quad (1)
\]

**A12.** Player 2’s payoff function:

\[
\pi_2(q) = F_2(q) + s_2qK_2 - C_2
\]

\[
= K_2^2(x_2a_2 - c_2)q^2 + K_2(x_2b_2 + x_2\lambda pK_1 + s_2 - d_2)q + x_2[a_2(pK_1)^2 + b_1pK_1] \quad (2)
\]
4 STATIC GAME WITH COMPLETE INFORMATION

On the basis of Eqs. (1) and (2), we can obtain marginal payoff function as 
\[ \pi_1'(p) = 2K_1^2(x_1a_1 - c_1)p + K_1(x_1b_1 + x_1\lambda qK_2 + s_1 - d_1) \]
for player 1, similarly,
\[ \pi_2'(q) = 2K_2^2(x_2a_2 - c_2)q + K_2(x_2b_2 + x_2\lambda pK_1 + s_2 - d_2) \]
for player 2. Given that \( x_1a_1 > c_1 \) and \( x_2a_2 > c_2 \), the marginal payoff of both players is increasing (e.g., enterprises set higher ERR (economic rate of return) at the beginning to start the task-based cooperation for knowledge sharing purpose, which leads to the increasing marginal payoff). Given that \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), the marginal payoff is decreasing or invariant (e.g., enterprises may set much lower level of ERR at the beginning as a result of good corporate culture, which will lead to decreasing marginal payoff; or enterprises may keep reducing ERR with the progress of task-based cooperation, which also leads to decreasing marginal payoff). Under this assumption, we analyze the knowledge sharing behavior between two players as a static game with complete information in the context of increasing marginal payoff, invariant marginal payoff and diminishing marginal payoff separately.

4.1 Scenarios When Marginal Payoff is Increasing or Invariant

Given that \( x_1a_1 > c_1 \) and \( 0 \leq p \leq 1 \), from Eqs. (1) and (2), the marginal payoff of player 1’s payoff function is increasing, which makes \( \pi_1(p) \) a strictly convex function and \( \text{Max}\{\pi_1(p)\} = \text{Max}\{\pi_1(0), \pi_1(1)\} \). Similarly, given that \( x_2a_2 > c_2 \) and \( 0 \leq q \leq 1 \), the marginal payoff of player 2’s payoff function is also increasing, which makes \( \pi_2(q) \) a strictly convex function and \( \text{Max}\{\pi_2(q)\} = \text{Max}\{\pi_2(0), \pi_2(1)\} \).

If \( x_1a_1 - c_1 \), \( \pi_1(p) \) is a linear function of \( p \) and \( \text{Max}\{\pi_1(p)\} = \text{Max}\{\pi_1(0), \pi_1(1)\} \) where \( 0 \leq p \leq 1 \). Similarly, if \( x_2a_2 - c_2 \) and \( 0 \leq q \leq 1 \), \( \pi_2(q) \) is a linear function of \( q \) and we have \( \text{Max}\{\pi_2(q)\} = \text{Max}\{\pi_2(0), \pi_2(1)\} \).

As a result, given \( x_1a_1 \geq c_1 \), \( x_2a_2 \geq c_2 \) and \( 0 \leq p \leq 1, 0 \leq q \leq 1 \), both players have two choices, complete defection or complete cooperation. Table 2 shows players’ payoff matrix when the marginal payoff is increasing or invariant.

<table>
<thead>
<tr>
<th>( p )</th>
<th>( q )</th>
<th>( x_1(a_1K_1^2 + b_1K_1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>( x_1(a_1K_1^2 + b_1K_1) ) + ( K_1(x_1b_1 + s_1 - d_1) )</td>
<td></td>
</tr>
<tr>
<td>0, 0</td>
<td>( x_1(a_1K_1^2 + b_1K_1) ) + ( K_1(x_1b_1 + s_1 - d_1) )</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>( K_1^2(x_1a_1 - c_1) + K_1(x_1b_1 + s_1 - d_1) )</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>( K_1^2(x_1a_1 - c_1) + K_1(x_1b_1 + s_1 - d_1) )</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>( K_1^2(x_2a_2 - c_2) + K_2(x_2b_2 + s_2 - d_2) )</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>( K_1^2(x_2a_2 - c_2) + K_2(x_2b_2 + s_2 - d_2) )</td>
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</table>

Table 1. Players’ payoff matrix

According to table 1, we can get the following scenarios of game equilibrium and propositions.

(1) The unique Nash equilibrium of \( \{p^* = 1, q^* = 1\} \)

**Proposition 1.** Given \( x_1a_1 \geq c_1 \), \( x_2a_2 \geq c_2 \), \( 0 \leq p \leq 1 \) and \( 0 \leq q \leq 1 \), \( \{p^* = 1, q^* = 1\} \) is the unique Nash equilibrium as long as
\[ s_1 > K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 - x_1 \lambda K_2 \] and \[ s_2 > K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 , \] or
\[ s_1 > K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 \] and \[ s_2 > K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 - x_2 \lambda K_1 . \]
Thus, both players will cooperate completely and contribute their TK (total knowledge).

(2) The unique Nash equilibrium of \( \{ p^* = 1, q^* = 0 \} \)

**Proposition 2.** Given \( x_1 a_1 \geq c_1 , x_2 a_2 \geq c_2 , 0 \leq p \leq 1 \) and \( 0 \leq q \leq 1 , \) \( \{ p^* = 1, q^* = 0 \} \) is the unique Nash equilibrium as long as
\[ s_1 > K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 \] and \[ s_2 < K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 - x_2 \lambda K_1 . \]
Thus, player 1 will cooperate completely and contribute TK while player 2 will do oppositely.

(3) The unique Nash equilibrium of \( \{ p^* = 0, q^* = 1 \} \)

**Proposition 3.** Given \( x_1 a_1 \geq c_1 , x_2 a_2 \geq c_2 , 0 \leq p \leq 1 \) and \( 0 \leq q \leq 1 , \) \( \{ p^* = 0, q^* = 1 \} \) is the unique Nash equilibrium as long as
\[ s_1 < K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 - x_1 \lambda K_2 \] and \[ s_2 > K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 . \]
Thus, player 1 will defect completely and contribute nothing while player 2 will do oppositely.

(4) The unique Nash equilibrium of \( \{ p^* = 0, q^* = 0 \} \)

**Proposition 4.** Given \( x_1 a_1 \geq c_1 , x_2 a_2 \geq c_2 , 0 \leq p \leq 1 \) and \( 0 \leq q \leq 1 , \) \( \{ p^* = 0, q^* = 0 \} \) is the unique Nash equilibrium as long as
\[ s_1 < K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 - x_1 \lambda K_2 \] and \[ s_2 < K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 - x_2 \lambda K_1 , \] or
\[ s_1 < K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 - x_1 \lambda K_2 \] and \[ s_2 < K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 . \]
Thus, both players will defect completely and contribute nothing.

(5) The Nash equilibrium of \( \{ p^* = 1, q^* = 1 \} \) and \( \{ p^* = 0, q^* = 0 \} \)

**Proposition 5.** Given \( x_1 a_1 \geq c_1 , x_2 a_2 \geq c_2 , 0 \leq p \leq 1 \) and \( 0 \leq q \leq 1 , \) we can get the Nash equilibrium of \( \{ p^* = 1, q^* = 1 \} \) and \( \{ p^* = 0, q^* = 0 \} \) as long as
\[ K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 - x_1 \lambda K_2 < s_1 < K_1(c_1 - x_1 a_1) + d_1 - x_i b_1 \] and
\[ K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 - x_2 \lambda K_1 < s_2 < K_2(c_2 - x_2 a_2) + d_2 - x_2 b_2 . \]
Thus one player will do the same as the other one. That is to say, whether one player chooses to cooperate completely or not, the other one will have the same choice, and vice versa.

### 4.2 Scenario When Marginal Payoff is Diminishing

(1) Solving the equilibrium solution

From Eqs. (1) and (2), we obtain that the marginal payoff of player 1’s payoff function is diminishing when \( x_1 a_1 < c_1 , \) which makes \( \pi_1 (p) \) a strictly concave function with a maximum value. Correspondingly, the marginal payoff of player 2’s payoff function is diminishing when \( x_2 a_2 < c_2 , \) which makes \( \pi_2 (q) \) a strictly concave function with a maximum value.

Taking the first-order differential on \( \pi_1 (p) \) and \( \pi_2 (q) \), that is \( \pi_1 '(p) = 0 \) as well as \( \pi_2 '(q) = 0 \), with respect to \( p \) and \( q \) results and we obtain the optimal solution \( p^* \) and \( q^* \) as equilibrium knowledge contribution effort (EKCE).
\[
p^* = \frac{2(s_1 + b_1x_1 - d_1) + \lambda x_1(b_2x_2 + s_2 - d_2)}{c_2 - a_2x_2} \cdot \frac{1}{K_1}
\]
\[
q^* = \frac{2(s_2 + b_2x_2 - d_2) + \lambda x_2(b_1x_1 + s_1 - d_1)}{4(c_2 - a_2x_2)} - \frac{x_1x_2\lambda^2}{(c_2 - a_2x_2)} \cdot \frac{1}{K_2}
\]

Considering the analysis above, we obtain the proposition 6.

**Proposition 6.** Given \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), \( \{p^*, q^*\} \) is the unique Nash equilibrium as long as \( 0 \leq p^* \leq 1 \) and \( 0 \leq q^* \leq 1 \).

If \( 0 \leq p^* \leq 1 \) and \( 0 \leq q^* \leq 1 \), require

\[0 \leq xb_1 + s_1 - d_1 + x_1\lambda qK_2 \leq 2(c_1 - x_1a_1)K_1 \]
\[0 \leq xb_2 + s_2 - d_2 + x_2\lambda pK_1 \leq 2(c_2 - x_2a_2)K_2.\]

If we don’t have \( 0 \leq p^* \leq 1 \) and \( 0 \leq q^* \leq 1 \), Proposition 6 does not hold. Suppose \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \) continue to be true. Here are some special cases:

- If \( p^* < 0 \) and \( q^* < 0 \), then \( \text{Max}[\pi_1(p)] = \pi_1(0) \) and \( \text{Max}[\pi_2(q)] = \pi_2(0) \). \( p^* = 0 \) and \( q^* = 0 \) are the new optimal strategies, that is similar to \( \{\text{completely defect, completely defect}\} \).
- If \( 0 \leq p^* \leq 1 \) and \( q^* < 0 \), then \( q^* = 0 \) is the new optimal strategy for player 2, that is similar to completely defect. And player 1 plays her/his optimal strategy \( p^* = (xb_1 + s_1 - d_1) / [2(c_1 - x_1a_1)K_1] \).
- If \( 0 \leq p^* \leq 1 \) and \( q^* > 1 \), then \( q^* = 1 \) is the new optimal strategies for player 2, that is similar to completely cooperate. And player 1 plays her/his optimal strategy \( p^* = (xb_1 + s_1 - d_1 + x_1\lambda K_2) / [2(c_1 - x_1a_1)K_1] \).
- If \( p^* > 1 \) and \( q^* > 1 \), then \( \text{Max}[\pi_1(p)] = \pi_1(1) \) and \( \text{Max}[\pi_2(q)] = \pi_2(1) \). \( p^* = 1 \) and \( q^* = 1 \) are the new optimal strategies, that is similar to \( \{\text{completely cooperate, completely cooperate}\} \).

Similar discussion can be extend to cases such as \( p^* < 0 \) and \( 0 \leq q^* \leq 1 \), and those cases where payoff functions Eqs. (1) and (2) are no longer concave.

(2)The relation between TK and EKCE

From Eqs. (3) and (4), we can infer that when other parameters remain unchanged, the lower \( K_1 \), the higher \( p^* \). Similarly, the lower \( K_2 \), the higher \( q^* \). Since \( K_1 \) is much higher than \( K_2 \), if the other parameters of both players are not very different, \( p^* \) is much lower than \( q^* \). In summary, we have

**Proposition 7.** If \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), an inverse relationship is found between both players’ EKCE and TK. That is, the more TK, the less EKCE. All other things being equal, we would like to point out that player 2 has great willingness to participate in the task-based cooperation in order to share knowledge, while player 1 would not like to contribute knowledge because of their abundant knowledge.

(3)The relation between PKC (productivity of knowledge contribution) and EKCE, ERR and EKCE, CRKC (cost rate of knowledge contribution) and EKCE.

As shown in Eqs. (3) and (4), we can point out that when other parameters remain unchanged, the
higher \( a_1 \) and \( b_1 \), the higher \( p^* \). Similarly, the higher \( a_2 \) and \( b_2 \), the higher \( q^* \). Thus,

**Proposition 8.** If \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), the higher PKC of both players, the higher EKCE.

From Eqs. (3) and (4), we can infer that when other parameters remain unchanged and \( b_2x_2 + s_2 - d_2 \geq 0 \), the higher \( x_1 \), the higher \( p^* \). Similarly when \( b_1x_1 + s_1 - d_1 \geq 0 \), the higher \( x_2 \), the higher \( q^* \). Thus, we have

**Proposition 9.** If \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), given \( x_2 \geq (d_2 - s_2) / b_2 \), the higher \( x_1 \), the more knowledge player 1 will contribute. Correspondingly, given \( x_1 \geq (d_1 - s_1) / b_1 \), the higher \( x_2 \), the more knowledge player 2 will contribute.

On the other hand, when other parameters remain unchanged, the lower \( c_1 \) and \( d_1 \), the higher \( p^* \). Similarly, the lower \( c_2 \) and \( d_2 \), the higher \( q^* \). Thus,

**Proposition 10.** Given \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), the lower cost to the players, the more knowledge they will contribute.

(4) The relation between SRR (social rate of return) and EKCE

When other parameters remain unchanged, the higher \( s_1 \), the higher \( p^* \). Similarly, the higher \( s_2 \), the higher \( q^* \). Thus we have

**Proposition 11.** Given \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), the higher social return to the players, the more knowledge they will contribute.

Specifically, considering \( p^*_1 = 1 \) and \( q^*_1 = 1 \), we can get

\[
s_1^* = \frac{(c_1-a_1)x}{4K((c_1-a_1)x) - Kx_1x_2\lambda^2 - 2(b_1x_1 - d_1) + 2Kx_1x_2\lambda^2 + (b_1x_1 - d_1) + \lambda x(b_1x_1 - d_1) / (c_1-a_1)x)}{(c_1-a_1)} \tag{5}
\]

\[
s_2^* = \frac{(c_1-a_1)x}{4K((c_1-a_1)x) - Kx_1x_2\lambda^2 - 2(b_1x_1 - d_1) + 2Kx_1x_2\lambda^2 + (b_1x_1 - d_1) + \lambda x(b_1x_1 - d_1) / (c_1-a_1)x)}{(c_1-a_1)} \tag{6}
\]

Players will contribute their TK in the task-based cooperation where \( s_1 \geq s_1^* \) and \( s_2 \geq s_2^* \), and then \{complete cooperation, complete cooperation\} is a unique equilibrium. We have the following observation.

**Proposition 12.** Given \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), players will contribute their TK only if they have enough social return (that is, when SRR reaches the critical value).

(5) The relation of CE (collaborative efficiency), ERR and EKCE

As shown in Eqs. (3) and (4), we would like to point out when other parameters remain unchanged and \( b_2x_2 + s_2 - d_2 \geq 0 \), the higher \( \lambda \), the higher \( p^* \). Similarly, when \( b_1x_1 + s_1 - d_1 \geq 0 \), the higher \( \lambda \), the higher \( q^* \). Thus,

**Proposition 13.** Given \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), player 1 will contribute more knowledge when players are more efficient to finish the task by cooperation as long as \( x_2 \geq (d_2 - s_2) / b_2 \). Similarly, player 2 will contribute more knowledge with higher \( \lambda \) as long as \( x_1 \geq (d_1 - s_1) / b_1 \).

## 5 ANALYSIS OF INCENTIVE MECHANISMS

On the basis of above static game analysis with complete information, we may discuss the possible incentive mechanisms to promote the knowledge sharing between senior employees and young ones.
(1) Building a great corporate culture

Proposition 1, where $x_1a_1 \geq c_1$ and $x_2a_2 \geq c_2$, gives us a scenario that $\{p^* = 1, q^* = 1\}$ is the unique and stable Nash equilibrium as long as

\[
s_1 > K_1(c_1 - x_1a_1) + d_1 - x_1b_1 - x_1\lambda K_1 \quad \text{and} \quad s_2 > K_2(c_2 - x_2a_2) + d_2 - x_2b_2,
\]

or

\[
s_1 > K_1(c_1 - x_1a_1) + d_1 - x_1b_1 \quad \text{and} \quad s_2 > K_2(c_2 - x_2a_2) + d_2 - x_2b_2 - x_2\lambda K_1.
\]

In order to make senior employees as well as young employees corporate completely and contribute their TK (total knowledge), enterprises may improve SRR (social rate of return) by building corporate culture of respecting knowledge, achievements, senior employees (especially those who are willing to share knowledge) (Slager 2007; Taylor et al. 1998) and creating a favorable learning and communicating atmosphere.

Given $x_1a_1 < c_1$ and $x_2a_2 < c_2$, we can infer from Proposition 11 that the higher social return employees gain while they complete the task, the more knowledge they will contribute. Thus, we can also improve EKCE (equilibrium knowledge contribution effort) of senior employees by creating a favorable atmosphere. So long as SRR reaches a critical value ($s_1^*$ for senior employees and $s_2^*$ for young ones), employees will contribute their TK.

(2) Reducing CRKC (cost rate of knowledge contribution), raising ERR (economic rate of return) or offering extra economic return

Generally, it’s difficult to create corporate culture fast. We can take the following methods to deal with “cold boot” (rare and short-lived spontaneous knowledge sharing) in the task-based cooperation.

1 Reducing CRKC by training

As Proposition 1 shows, if $x_1a_1 \geq c_1$ and $x_2a_2 \geq c_2$, the lower CRKC, the lower SRR players will need to cooperate completely. In addition, if $x_1a_1 < c_1$ and $x_2a_2 < c_2$, we can point out from Proposition 10 that the higher CRKC, the lower EKCE. Employees’ knowledge contribution cost may include the cost of learning, expressing, teaching, managing and applying knowledge as well as interpersonal relationship. Therefore, enterprises need to train employees, especially senior employees, on knowledge expression, teaching, management and application, which will help reduce the CRKC (especially that of senior employees). Besides, familiar ways of communication (such as face-to-face communication) should be provided to senior employees for better cooperation with young ones, so that cost of interpersonal relationship will be reduced. What we mentioned above contributes to reduce CRKC and raise employees’ EKCE.

2 Raising ERR

Proposition 1, where $x_1a_1 \geq c_1$ and $x_2a_2 \geq c_2$, suggests that the higher ERR, the lower SRR players will need to cooperate completely. If $x_1a_1 < c_1$ and $x_2a_2 < c_2$, we can infer from Proposition 9 that the higher ERR of senior employees, the higher of their EKCE as long as $x_2 \geq (d_2 - s_2)/b_2$. Similarly, the higher ERR of young employees, the higher of their EKCE as long as $x_1 \geq (d_1 - s_1)/b_1$. Therefore, under certain conditions, raising ERR can promote senior and young employees to contribute knowledge.

3 Offering extra economic return

From Proposition 1 and Proposition 12, employees will contribute their TK if SRR reaches the critical value. However, different employees may have different sense of SRR. And it’s time-consuming to raise SRR by creating good corporate culture. Thus enterprises would like to offer extra economic return (ERER) for the unit of knowledge, the total amount of compensation for knowledge contribution is $i_1pK_1$. Similarly, $i_2$ represents the ERER of player 2, and the compensation is $i_2qK_2$.

When $x_1a_1 \geq c_1$ and $x_2a_2 \geq c_2$, according to Proposition 1, the premise of players’ complete
cooperation is

\[ s_1 + i_1 > K(c_1 - x(a_1) + d_1 - x(b_1 - x_1)K_2 \text{ and } s_2 + i_2 > K(c_2 - x_2a_2 + d_2 - x_2b_2), \]

or

\[ s_1 + i_1 > K(c_1 - x(a_1) + d_1 - x_1b_1 + x_1)K_2 \text{ and } s_2 + i_2 > K(c_2 - x_2a_2 + d_2 - x_2b_2 - x_2K_1) \]

Thus, enterprises can increase \( i_1 \) and \( i_2 \) to make senior employees and young ones cooperate completely under the condition of lower \( s_1 \) and \( s_2 \).

Specifically, if \( x_1a_1 < c_1 \) and \( x_2a_2 < c_2 \), (3) and (4) are transformed to

\[
p^* = \frac{2(s_1 + i_1 + b_1x_1 - d_1) - \lambda x_1(d_2 - b_2x_2 - s_2)}{c_2 - a_2x_2} \cdot \frac{1}{K_1} \\
q^* = \frac{2(s_2 + i_2 + b_2x_2 - d_2) - \lambda x_2(d_1 - b_1x_1 - s_1)}{c_1 - a_1x_1} \cdot \frac{1}{K_2}
\]

From Eqs. (7) and (8), we can infer that enterprises may improve \( i_1 \) so that \( s_1 + i_1 \) will reach the critical value where senior employees will contribute their TK when \( s_1 \) is low. Similarly, enterprises may improve \( i_2 \) so that \( s_1 + i_1 \) will reach the critical value where young employees will contribute their TK when \( s_2 \) is low.

Proposition 1 delivers a message that as cooperation progresses, CE (collaborative efficiency), SRR and TK of employees will increase, when less ERR (including ERER) can meet the conditions of complete cooperation. Particularly, young employees can learn much knowledge from senior ones and their TK will improve greatly, which makes even a significant reduction of senior employees’ ERR (including ERER) will meet the conditions of their complete cooperation.

According to Proposition 13, CE will increase with the progress of cooperation if \( x_2 \geq (d_2 - s_2)/b_2 \), and the critical value of SRR that senior employees need to contribute completely will decrease.

Thus, enterprises may reduce senior employees’ ERR (including ERER) with the progress of cooperation if \( x_2 \geq (d_2 - s_2)/b_2 \). Correspondingly, as cooperation progresses, the ERR (including ERER) of young employees can be reduced if \( x_1 \geq (d_1 - s_1)/b_1 \).

6 DISCUSSION

In this paper, we analyze the relation of players’ EKCE (equilibrium knowledge contribution effort), benefit (ERR (economic rate of return), SRR (social rate of return)) and cost (CRKC (cost rate of knowledge contribution)) in the task-based cooperation. Promoting the knowledge transfer from senior employees to young ones is conducive to solve the problem of knowledge loss caused by the aging of population. As the critical knowledge of senior employees is tacit knowledge, we come up with a context of task-based cooperation for the purpose of knowledge sharing and utilize game theory to analyze KCE (knowledge contribution effort) of both players, and then gain different Nash equilibrium solutions under different conditions.

Assuming that the marginal payoff keeps increasing or invariant in the task-based cooperation, we find that both senior employees and young ones will have two choices, complete cooperation or complete defection, which are consistent with the existing game assumption (Samieh et al. 2007; Cabrera et al. 2002 etc.). Unlike extant literature, we propose the premise condition of those assumptions. While the marginal payoff is diminishing, however, we find players have three choices: complete defection, complete cooperation and partial cooperation.

This paper shows that SRR has positive effects on EKCE of both senior players and young ones in the
task-based cooperation, which is proved by using game theory. That finding is consistent with the results of existing empirical studies that social return (such as respect, enjoyment in helping others) has a positive impact on employees’ knowledge sharing and transfer (Yan et al. 2013; Cruz et al. 2009 etc.). Specifically, the critical value where players will contribute their TK (total knowledge) and how it will be affected by ERR and CRKC are analyzed through using game theory in this paper, which is helpful for enterprises to design effective incentive mechanisms.

When the marginal payoff of employees’ knowledge contribution is increasing or invariant, we can infer that the critical value of SRR is negatively related to players’ ERR and positively related to cost through game analysis, which is in good agreement with existed conclusions that employees’ knowledge sharing intention is positively related to economic return, and negatively related to cost. (Slagter 2007; Delong 2004 etc.). In addition, we point out that there is a “substitution relation” between SRR and ERR. If it’s difficult to raise SRR in the short term, enterprises can reduce the critical value of SRR through higher ERR to promote cooperation and knowledge sharing. As cooperation progresses, CE (collaborative efficiency), SRR and young employees’ TK will increase, thus enterprises may reduce economic return (ERR) properly.

In the context of diminishing marginal payoff of players, we can get the equilibrium solution of KCE in the task-based cooperation between senior employees and young ones. Therefore, we point out the negative correlation between TK and KCE according to the equilibrium solution, and senior employees are lacking of motivation to contribute knowledge because of their vast amount of that. But Noethen (2011) find that senior employees have strong willingness to contribute their knowledge. The contradictory probably results from the rationality and diminishing marginal payoff assumptions in our paper. Under conditions of high CRKC, although senior employees can gain economic return as well as social return by contributing knowledge, the KCE will decrease with the increasing of TK as a result of diminishing marginal payoff, which is in accord with the conclusion suggested by Cai et al. (2009) that the equilibrium effort in e-collaboration is inversely proportional to participators’ total resource. Furthermore, the equilibrium solution shows that the improvement of KCE is positively related to SRR and PKC (productivity of knowledge contribution) and negatively related to CRKC, which has a good agreement with the existed conclusion about factors of knowledge sharing among employees (Slagter 2007; Delong 2004 etc.).

7 CONCLUSION

7.1 Implications

Firstly, we extend the e-collaboration game model built by Cai et al. (2009) and apply it to the context of task-based cooperation between senior employees and young ones with the goal of knowledge sharing, which contributes to understanding the decision-making process of knowledge contribution under specific context. In this paper, the social punishment and punishment mechanism of discrete-strategy e-collaboration games is adjusted to social return and incentive mechanism, promoting senior employees to contribute more knowledge in the task-based cooperation. Besides, we emphasize the difference between the SRR (social rate of return) of senior employees and that of young ones. We also analyze the equilibrium solutions of KCE (knowledge contribution effort) in the context of increasing, invariant or diminishing marginal payoff, enhancing the understanding toward task-based cooperation.

Secondly, we can gain some insights into affecting factors and incentive mechanisms of knowledge sharing between senior employees and young ones by game theoretic analysis. Previous research has proved that social rewards such as involvement, sense of belonging and autonomy in the performance of activities (Cruz et al. 2009), enjoyment in helping others and sense of self-worth (Yan et al. 2013), respect for individual knowledge (Delong 2004), as well as economic rewards such as the material return (Cruz et al. 2009; Hsu 2006) have positive impacts on employees’ knowledge sharing and transfer. But the analysis of critical value of social rewards and that of economic rewards to make employees contribute their TK (total knowledge), as well as the analysis of different influence processes and conditions of different incentive mechanisms are very limited, and those are what we
have discussed in this paper. We also point out that different economic rewards have different mechanisms under different conditions. When the marginal payoff of senior employees’ knowledge contribution is diminishing, for example, higher senior employees’ ERR (economic rate of return) will have completely positive effect on their EKCE (equilibrium knowledge contribution effort) only if young employees’ ERR, PKC (productivity of knowledge contribution) and CRKC (cost rate of knowledge contribution) have particular relations. However, the incentive mechanism that offering extra economic return to employees with low SRR is free from constraints.

Lastly, the problem of insufficient SRR can be solved by extra economic compensation, which also provides method to deal with “cold boot”. If the marginal payoff is increasing or invariant, players may choose complete cooperation or defection. Thus employees cannot cooperate effectively because of the SRR lower than the critical value. Previous studies have proved that it is difficult to build corporate culture (Slater 2007; Cater 2004), and economic incentives (such as raising ERR, offering extra economic return) are required to start knowledge sharing to prevent “cold boot”. Not only the SRR will increase with the formation of atmosphere of respecting senior employees, the EC, the young employees’ TK and the PKC will also increase with the progress of cooperation. Thus, enterprises may reduce economic return in stage focusing on social rewards and cooperation, bringing forth a culture of knowledge sharing.

In summary, we design some incentive mechanisms for promoting the knowledge contribution of senior employees according to different equilibrium solutions under different conditions, which can provide enterprises with guidance in encouraging task-based cooperation for knowledge sharing and help them make effective decisions such as when to raise economic return or when to reduce, and how many economic rewards are fairly enough.

7.2 Future Work

Promoting knowledge sharing from senior employees to young ones can be very helpful in dealing with knowledge loss in enterprises as a result of the aging population, and knowledge can be transferred from senior employees to young ones in the task-based cooperation for purpose of knowledge sharing. In this paper, we focus on the relation of KCE, benefit (ERR, SRR) and cost (CRKC) in the context of task-based cooperation and analyze a static game with complete information and gain the equilibrium solutions when marginal payoff is increasing, invariant or diminishing.

Although we get some findings, there are several limitations in our study. First, for simplifying the study, we assume that the benefit function of knowledge contribution is a quadratic function, as is the cost function. So the future research can make comprehensive comparison and analysis on various possible functions for benefit and cost. Second, we have static game analysis with complete information based on assumption of rational man. In fact, however, it’s almost impossible for employees to understand parameters of others. And the task-based cooperation is in a dynamic process. The future research can focus on static game analysis with incomplete information or dynamic game analysis. Third, we analyze only for knowledge sharing among employees in the context of task-based cooperation, and scenarios when senior employees transfer knowledge just as mentors can be discussed in future work. Last, since our findings are not evaluated in the real case, case study and empirical research (such as survey and experiment study) methods may be used to verify and evaluate our conclusions in future work.

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