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Research on knowledge transfer behaviour in cooperative innovation and simulation

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ABSTRACT

This paper constructs an evolutionary game model of team members' knowledge transfer behaviour with reciprocal preference in team innovation activities, studies the strategy selection of team members, and simulates the evolution equilibrium strategy of the model with different parameter changes. The results show that the proportion of initial reciprocal actors, the proportion of sharing, and the degree of knowledge complementation are all conducive to the formation of reciprocal cooperation of knowledge transfer, while the work conflict is just the opposite. In addition, the influence of reciprocal preference on evolutionary equilibrium is related to the spreads in reciprocity and self-interested behaviour. This paper extends the research on the reciprocal cooperation of knowledge team from the perspective of behavioural economics.

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1. Introduction

Knowledge is the foundation of innovation. Knowledge flow is the driving force of team innovation activities. It plays a key role in promoting organisational learning, gathering individual knowledge of employees into organisational knowledge to establish and enhance organisational competitive advantage (Nonaka, 1994). 'Open innovation' proposed by Chesbrough (2011), is to absorb the internal and external diversity of knowledge actively in the process of innovation (Chesbrough, 2011). The integration of diversified and heterogeneous knowledge has a significant positive impact on improving team innovation performance. Polanyi divided knowledge into explicit knowledge and tacit knowledge, and considered that tacit knowledge is the subject of knowledge with characteristics of non-coding and monopoly. Therefore, for the knowledge output, knowledge transfer to knowledge acquirers is a self-sacrifice (labour but may not be rewarded) activities, individual always have the enthusiasm to become a knowledge acquirer rather than a knowledge writer. At the same time, because of the individual or the organisational control and security needs, the lack of mutual trust, the loss of

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knowledge power and other reasons, the transfer of knowledge is not smooth, which hindered the activities of innovation to some extent (Weidong & Hong, 2014).

The material incentive can effectively promote the knowledge sharing among team members, but the role of informal contract cannot be ignored. Public goods games found that reciprocity theory can explain the existence of significant public goods supply in part (Yean & Zifeng, 2008). Traditional economics assumes that human is rational and self-interest, but many examples in life cannot be explained by pure self-interest, such as people's voluntary contributions, sacrificing self-interests to punish others. In knowledge transfer, we can often see that some people are willing to sacrifice their time and energy to teach others even if there is no direct return, some people prefer to give up the extra benefits brought by cooperation, and do not want to share knowledge with colleagues. Reciprocal preferences play a role in this. Reciprocal preference means that people often respond to others' intentions or motive a certain behaviour. When he feels that others are full of goodwill to himself, he will also return to them in good faith; when he feels that others are malicious to himself, then he will also give them a malicious return, even if this action requires a certain price. So the knowledge transfer behaviours in teams' innovation activities are also affected by individual reciprocity preferences. In recent years, with the rise of behavioural economics, research on reciprocity and knowledge sharing or knowledge transfer has gradually increased, and concentrated in the following aspects: Reciprocity has a significant positive impact on knowledge sharing, knowledge acquisition and knowledge contribution (Haixin & Renjing, 2014; Hejiang, 2014; Weidong & Hong, 2014); reciprocal norms have a significant positive impact on knowledge sharing, knowledge contribution and knowledge search behaviour (Changping & Li, 2015; Zhimin, Jiangle, & Yiping, 2014); reciprocal preference can effectively promote the transformation of tacit knowledge within the R & D team and further improve the team technological innovation capacity (Tongjian, 2010; Tongjian & Yongjian, 2010). In terms of the choice of reciprocal behaviour, some scholars believe that risk appetite affects the choice of reciprocal behaviour (Guo, Ershi, & Liang, 2015), but this behaviour should also be affected by the reciprocity preferences of the actors themselves (Chunchun, Congying, & Ye-An, 2015).

In the team innovation activities, whether it is knowledge sharing, knowledge contribution or knowledge search, its essence is to achieve the transfer of knowledge. This cooperative and mutually beneficial behaviour–knowledge transfer, is closely related to the individual bounded rationality of the reciprocity preferences. Therefore, there is a certain deviation if the traditional game theory based on complete rational hypothesis is used to study the behaviour. At the same time in the team innovation activities, the collision of knowledge is not a one-time, but continues to occur repeatedly between the different individuals, and the optimal strategy is gradually being adopted by more and more individuals in this process. So It is more realistic and theoretical using evolutionary game theory to analyze knowledge transfer behaviour of bounded rational participants.

Therefore, based on the preference of individual reciprocity, this paper analyzes the evolution of knowledge transfer among members in team innovation activities, and provides a reference for knowledge-based enterprises or teams to promote knowledge accumulation and creation and improve innovation efficiency.

2. Model

2.1. Hypotheses

H1: There are N members with bounded rationality in a knowledge team to carry out innovative activities. The members have heterogeneous knowledge and reciprocity preferences.

H2: Efforts by any team member include individual work efforts $x_i$and knowledge transfer efforts to others y_i, and the efforts cost function of team members is $C(x_i, y_i) = \frac{x_i^2}{2} + \frac{y_i^2}{2} + \Lambda x_i y_i$, with $C'>0, C''>0$, while $x_i \geq 0, y_i \geq 0$, and $\Lambda \in (0[\text{elinters}]1)$ is the conflict coefficient between individual work efforts and knowledge transfer efforts. When $\Lambda = 0$, there is no conflict between the two efforts, and when $\Lambda = 1$, there is a complete conflict between the two efforts (Kretschmer & Puranam, 2008).

H3: The team members are randomly assigned to transfer knowledge, and the output of team members π_i is determined by individual work efforts and the knowledge transfer efforts of the matching members. The knowledge transfer of other members to the team member expands the knowledge width or depth of the member to a certain extent, which is conducive to the improvement of personal output. We use the linear relationship to describe the relationship between knowledge transfer effort and output, which can effectively express the relationship and does not make the model too complicated. The output function is $\pi_i = x_i + \mu y_j + \varepsilon_i$, while μ shows the impact coefficient of the matching member's knowledge transfer on the output of the member, that is, the degree of knowledge complementation. Without loss of generality, we simplify the knowledge complementarity of members of the same team to the same level and $\mu \geq 0$. ε_i is an exogenous variable that is not controlled by team members, and has a normal distribution with a mean of 0 and a variance of σ^2. The exogenous random factors faced by each member are equally distributed and independent.

H4: The total output of the team is the sum of the individual outputs of the team members: $\pi = \sum_{i=1}^{n} \pi_i$. The team member's salary income is $\omega(\pi) = \alpha + \beta\pi$, where α is the fixed income part, β is the percentage of individual dividends produced by the team, and it satisfies $\sum \omega(\pi) \leq \pi$.

H5: The strategy choice of the team members is uncertain, some members choose reciprocity behaviour, that is, transfer knowledge to others, while the other part of the members chooses self-interest behaviour, that is, do not transfer knowledge. But each member is willing to accept the transfer of knowledge to improve innovation output.

2.2. Reciprocal preference effect (Rabin, *1993*)

Rabin (1993) constructed a two-person game model with reciprocal intentions based on the 'psychological game theory' of Geanakoplos, Pearce and Satcchetti (1989), namely the motivation fair model. He argued that the welfare implications of fairness can be large, both because concern for fairness affects behaviour, and because it changes a person's utility for a given outcome. Rabin considered that people wish to help those who are helping them, and hurt those who are hurting them. He defined a 'kindness function', which links the effectiveness of the participants to strategies that others might implement. Rabin motivation fairness model portrays the influence of reciprocal preferences from the perspective of utility, and provides a reference for the study of participants' strategic. Therefore, this paper uses the Rabin motivational fair game model to correct the utility of players.

Definition 1. Consider a two-player, normal-form game with (mixed) strategy sets S_i and S_j for players i and j, derived from finite pure-strategy sets A_i and A_j. Let $\pi_i : S_i \times S_j \to R$ be player i's material payoffs. Throughout, we shall use the following notation: $a_i \in S_i$ and $a_j \in S_j$ represent the strategies chosen by the two players; $b_i \in S_i$ and $b_j \in S_j$ represent, respectively, player j's beliefs about what strategy player 1 is choosing, and player i's beliefs about what strategy player j is choosing; $c_i \in S_i$ and $c_j \in S_j$ represent player i's beliefs about what player j believes player i's strategy is, and player j's beliefs about what player i believes player j's strategy is.

Definition 2: Playeri's kindness to player j is given by $f_i(a_i, b_j) = \frac{\pi_j(a_i,b_j)-\pi_j^e(b_j)}{\pi_j^{\max}(b_j)-\pi_j^{\min}(b_j)}$

If $\pi_j^{\max}(b_j)-\pi_j^{\min}(b_j) = 0$, then $f_i(a_i, b_j) = 0$. If player i thinks player j chooses strategy b_j, we account for $\pi_j^{\max}(b_j)$ as the highest income of player j in $\prod(b_j)$, $\pi_j^{\min}(b_j)$ is the lowest possible income of player j in $\prod(b_j)$, $\pi_j^e(b_j)$ is the equal income of player j, and is satisfied $\pi_j^e(b_j) = \frac{\pi_j^{\max}(b_j)+\pi_j^{\min}(b_j)}{2}$.

Definition 3: Player i's belief about how kind player j is being to him is given by $\tilde{f}_j(b_j, c_i) = \frac{\pi_i(c_i,b_j)-\pi_i^e(c_i)}{\pi_i^{\max}(c_i)-\pi_i^{\min}(c_i)}$.

If $\pi_i^{\max}(c_i)-\pi_i^{\min}(c_i) = 0$, then $\tilde{f}_j(b_j, c_i) = 0$. $f_i(\bullet)$ and $\tilde{f}_j(\bullet) \in [-1, 1/2]$.

Definition 4: The pair of strategies $(a_i, a_j) \in (S_i, S_j)$ is a Fairness Equilibrium, then $\begin{cases} a_i \in \operatorname{argmax}_{a \in S_i} U_i(a, b_j, c_i) \\ c_i = b_i = a_i \end{cases}$.

That is, a group of strategies that give each other the best response to each other, and the beliefs at all levels are consistent with the actual strategy choices.

Definition 5: Each player i maximise his expected which incorporates both his material utility and the utility players' shared notion of fairness:

$$U_i(a_i, b_j, c_i) = \pi_i(a_i, b_j) + \gamma \cdot \tilde{f}_j(a_i, b_j) \cdot [1 + f_i(b_j, c_i)], \gamma \geq 0 \quad (1)$$

The reciprocal preference intensity coefficient γ characterises the effect of the participant's reciprocity preference on its utility (Guodong & Yongjian, 2011). When $\gamma = 0$, it is shown that the participant is purely self-interested, and the larger the γ, the greater the utility of the reciprocal motivator to the participant is relative to the material utility.

3. Evolutionary game

3.1. The material benefits of players

In innovation activity, knowledge transfer is the process of players to share their own knowledge with others. Team members have two strategies in innovation activities. One is to cooperate with others and transfer knowledge to other members. We call it reciprocal behaviour, denoted by H. And another does not transfer knowledge to others, but accept knowledge from others. We call it self-interested behaviour, denoted by L. As E_i is player i's expected utility.

Take the game of two people as an example. Randomly matching members i and j randomly choose whether to carry out knowledge transfer to each other, $E_i[\text{elinters}]H, H[\text{elinters}]$ means that when i selects strategy H, j also selects strategy H, the expected utility of player i without considering reciprocity preference.

$$\begin{aligned} E_iH, H &= E\left[\omega(\pi) - C(x_i, y_i)\right] = E\left[\alpha + \beta(\pi_i + \pi_j) - \left(\frac{x_i^2}{2} + \frac{y_i^2}{2} + \varepsilon_i\right)\right] \\ &= \alpha + \beta[(x_i + x_j) + \mu(y_i + y_j)] - \frac{x_i^2}{2} - \frac{y_i^2}{2} - \Lambda x_i y_i \end{aligned} \tag{2}$$

Similarly, we can get the material benefit matrix of players i and j under different strategies like formulas (2), as shown in Table 1.

$$E_i(H, L) = \alpha + \beta[(x_i + x_j) + \mu y_{\mathrm{i}}] - \frac{x_i^2}{2} - \frac{y_i^2}{2} - \Lambda x_i y_i$$

$$E_i(L, H) = \alpha + \beta[(x_i + x_j) + \mu y_{\mathrm{j}}] - \frac{x_i^2}{2}$$

$$E_i(L, L) = \alpha + \beta(x_i + x_j) - \frac{x_i^2}{2}$$

$$\begin{aligned} E_j[\text{elinters}]H, H[\text{elinters}] &= E\left[\omega(\pi) - C(x_j, y_j)\right] = E\left[\alpha + \beta(\pi_i + \pi_j) - \left(\frac{x_j^2}{2} + \frac{y_j^2}{2} + \varepsilon_j\right)\right] \\ &= \alpha + \beta[(x_i + x_j) + \mu(y_i + y_j)] - \frac{x_j^2}{2} - \frac{y_j^2}{2} - \Lambda x_j y_j \end{aligned}$$

$$E_j(H, L) = \alpha + \beta[(x_i + x_j) + \mu y_{\mathrm{i}}] - \frac{x_j^2}{2}$$

$$E_j(L, H) = \alpha + \beta[(x_i + x_j) + \mu y_j] - \frac{x_j^2}{2} - \frac{y_j^2}{2} - \Lambda x_j y_j$$

Table 1. Material Benefit Matrix.

	H	L
H	$\alpha + \beta[(x_i + x_j) + \mu(y_i + y_j)] - \frac{x_i^2}{2} - \frac{y_i^2}{2} - \Lambda x_i y_i$ $\alpha + \beta[(x_i + x_j) + \mu(y_i + y_j)] - \frac{x_j^2}{2} - \frac{y_j^2}{2} - \Lambda x_j y_j$	$\alpha + \beta[(x_i + x_j) + \mu y_{\mathrm{i}}] - \frac{x_i^2}{2} - \frac{y_i^2}{2} - \Lambda x_i y_i$ $\alpha + \beta[(x_i + x_j) + \mu y_{\mathrm{i}}] - \frac{x_j^2}{2}$
L	$\alpha + \beta[(x_i + x_j) + \mu y_j] - \frac{x_i^2}{2}$ $\alpha + \beta[(x_i + x_j) + \mu y_j] - \frac{x_j^2}{2} - \frac{y_j^2}{2} - \Lambda x_j y_j$	$\alpha + \beta(x_i + x_j) - \frac{x_i^2}{2}$ $\alpha + \beta(x_i + x_j) - \frac{x_j^2}{2}$

$$E_j(L,L) = \alpha + \beta(x_i + x_j) - \frac{x_j^2}{2}$$

3.2. The benefits of players based on reciprocity preferences

The Rabin Motivational Equity Model is used to correct the expected utility of players with reciprocal preferences. To simplify the analysis, we assume that the team players are homogeneous and therefore $x_1 = x_2 = x, y_1 = y_2 = y$.

Both player i and player j select strategy H: According to the fair equilibrium hypothesis, the belief at all levels is consistent with the actual strategy selection. The player i thinks that the player j chooses the strategy H, then he can give the player j the highest possible income is $E_j(H,H) = \alpha + \beta(2x + 2\mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy$, the lowest possible income is $E_j(H,L) = \alpha + \beta(2x + \mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy$, the equal income is $\frac{E_j(H,H)+E_j(H,L)}{2}$. Player i actually chooses strategy H, corresponding to the actual income of player j is $\alpha + \beta(2x + 2\mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy$. Player i's kindness to player j is

$$f_i(H,H) = \frac{\pi_j(H,H) - \pi_j^e(H)}{\pi_j^{\max}(H) - \pi_j^{\min}(H)} = \frac{E_j(H,H) - \left(E_j(H,H) + E_j(H,L)\right)/2}{E_j(H,H) - E_j(H,L)} \tag{3}$$

So how kindness does the player i think the player j to him?

When player i chooses strategy H, the highest possible income player j can give player i is $E_i(H,H) = \alpha + \beta(2x + 2\mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy$, the lowest possible income is $E_i(H,L) = \alpha + \beta(2x + \mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy$, the equal income is $\frac{E_i(H,H)+E_i(H,L)}{2}$. Player j actually chooses strategy H, corresponding to the actual income of player i. Player i's belief about how kind player j is being to him is:

$$\tilde{f}_j(H,H) = \frac{\pi_i(H,H) - \pi_i^e(H)}{\pi_i^{\max}(H) - \pi_i^{\min}(H)} = \frac{E_i(H,H) - (E_i(H,H) + E_i(H,L))/2}{E_i(H,H) - E_i(H,L)} \tag{4}$$

According to formulas (1) and take (3), (4) into the utility function, simplify:

$$\begin{aligned} U_i(H,H) &= E_i(H,H) + \gamma \cdot f_j(H,H) \cdot [1 + f_i(H,H)] \\ &= \alpha + \beta(2x + 2\mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy + \frac{3}{4}\gamma \end{aligned} \tag{5}$$

Similarly available:

$$U_i(H,L) = \alpha + \beta(2x + \mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy - \frac{3}{4}\gamma$$

$$U_i(L,H) = \alpha + \beta(2x + \mu y) - \frac{x^2}{2} + \frac{1}{4}\gamma$$

Table 2. Benefit Matrix Based On Reciprocal Preferences.

	H	L
H	$\alpha+\beta(2x+2\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy+\frac{3}{4}\gamma$ $\alpha+\beta(2x+2\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy+\frac{3}{4}\gamma$	$\alpha+\beta(2x+\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy-\frac{3}{4}\gamma$ $\alpha+\beta(2x+\mu y)-\frac{x^2}{2}+\frac{1}{4}\gamma$
L	$\alpha+\beta(2x+\mu y)-\frac{x^2}{2}+\frac{1}{4}\gamma$ $\alpha+\beta(2x+\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy-\frac{3}{4}\gamma$	$\alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma$ $\alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma$

$$U_i(L,L)=\alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma$$

We write a new benefit matrix based on reciprocal preferences for players, as shown in Table 2.

3.3. Model solving

U_H is the average utility of the player in the choice strategy H, U_L is the average utility of the player in the selection strategy L, $\bar{U}$ is the average utility of the total game player, and s is the proportion of the player who contributes the knowledge transfer behaviour to the whole group.

$$\begin{aligned} U_H &= s\left[\alpha+\beta(2x+2\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy+\frac{3}{4}\gamma\right] \\ &\quad +(1-s)\left[\alpha+\beta(2x+\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy-\frac{3}{4}\gamma\right] \\ &= \alpha+\beta(2x+\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy-\frac{3}{4}\gamma+s\left(\beta\mu y+\frac{3}{2}\gamma\right) \end{aligned} \tag{6}$$

$$\begin{aligned} U_L &= s\left[\alpha+\beta(2x+\mu y)-\frac{x^2}{2}+\frac{1}{4}\gamma\right]+(1-s)\left[\alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma\right] \\ &= \alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma+s\left(\beta\mu y+\frac{1}{2}\gamma\right) \end{aligned} \tag{7}$$

Take formulas (6) and (7) into average utility:

$$\begin{aligned} \bar{U} &= sU_H+(1-s)U_L \\ &= s\left[\alpha+\beta(2x+\mu y)-\frac{x^2}{2}-\frac{y^2}{2}-\Lambda xy-\frac{3}{4}\gamma+s\left(\beta\mu y+\frac{3}{2}\gamma\right)\right] \\ &\quad +(1-s)\left[\alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma+s\left(\beta\mu y+\frac{1}{2}\gamma\right)\right] \\ &= \alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma+s\left(\beta\mu y+\frac{1}{2}\gamma\right)+s\left(\beta\mu y-\frac{y^2}{2}-\Lambda xy-\frac{1}{2}\gamma+s\gamma\right) \\ &= \alpha+\beta(2x)-\frac{x^2}{2}-\frac{1}{4}\gamma+s\left(2\beta\mu y-\frac{y^2}{2}-\Lambda xy+s\gamma\right) \end{aligned} \tag{8}$$

The replication dynamic model can be obtained by using formulas (6) and (8):

$$\begin{aligned}
F(s) &= s(U_H - \bar{U}) \\
&= s\left\{\begin{array}{l} \alpha + \beta(2x+\mu y) - \frac{x^2}{2} - \frac{y^2}{2} - \Lambda xy - \frac{3}{4}\gamma + s\left(\beta\mu y + \frac{3}{2}\gamma\right) \\ -\left[\alpha + \beta(2x) - \frac{x^2}{2} - \frac{1}{4}\gamma + s\left(2\beta\mu y - \frac{y^2}{2} - \Lambda xy + s\gamma\right)\right] \end{array}\right\} \\
&= s\left[\beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma + s\left(-\beta\mu y + \frac{3}{2}\gamma + \frac{y^2}{2} + \Lambda xy - s\gamma\right)\right] \\
&= s\left[-\gamma s^2 + \left(-\beta\mu y + \frac{3}{2}\gamma + \frac{y^2}{2} + \Lambda xy\right)s + \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma\right] \\
&= -s\left[\gamma s + \left(\beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma\right)\right](s-1)
\end{aligned}$$

Let $F(s) = 0$, we can get three critical points:

$$s_1 = 0$$

$$s_2 = \frac{-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma}{\gamma}$$

$$s_3 = 1$$

Find the first derivative of $F(s)$:

$$F'(s) = -3\gamma s^2 + 2\left(-\beta\mu y + \frac{3}{2}\gamma + \frac{y^2}{2} + \Lambda xy\right)s + \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma$$

Then

$$F'(s_1) = F'(0) = \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma$$

$$\begin{aligned}
F'(s_2) = F'\left(\frac{-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma}{\gamma}\right) &= -3\gamma\left(\frac{-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma}{\gamma}\right)^2 \\
+2\left(-\beta\mu y + \frac{3}{2}\gamma + \frac{y^2}{2} + \Lambda xy\right)&\left(\frac{-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma}{\gamma}\right) + \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma \\
&= \frac{\left(-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma\right)\left(\beta\mu y - \frac{y^2}{2} - \Lambda xy + \frac{1}{2}\gamma\right)}{\gamma}
\end{aligned}$$

$$\begin{aligned}
F'(s_3) = F'(1) &= -3\gamma + 2\left(-\beta\mu y + \frac{3}{2}\gamma + \frac{y^2}{2} + \Lambda xy\right) + \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma \\
&= -\beta\mu y + \frac{y^2}{2} + \Lambda xy - \frac{1}{2}\gamma
\end{aligned}$$

4. Knowledge transfer behaviour evolution stability analysis

We mark Δ^{H}_{H-L} for the spreads in reciprocity and self-interested behaviour when the other party chooses the reciprocal behaviour, and Δ^{H}_{H-L} for the spreads in reciprocity and self-interested behaviour when the other party chooses self-interested behaviour.

$$\Delta^{H}_{H-L} = U_i(H,H) - U_i(L,H) = U_j(H,H) - U_j(H,L) = \beta\mu y - \frac{y^2}{2} - \Lambda xy + \frac{1}{2}\gamma$$

$$\Delta^{L}_{H-L} = U_i(H,L) - U_i(L,L) = U_j(L,H) - U_j(L,L) = \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma$$

Obviously, $\Delta^{H}_{H-L} - \Delta^{L}_{H-L} = \gamma \geq 0$, equal to $\Delta^{H}_{H-L} \geq \Delta^{L}_{H-L}$.

Conclusion 1: When $\beta\mu y - \frac{y^2}{2} - \Lambda xy + \frac{1}{2}\gamma < 0$, i.e.,$\Delta^{L}_{H-L} \leq \Delta^{H}_{H-L} < 0$, the evolution of the group will evolve into a stable strategy $s_1 = 0$, there will not exist knowledge transfer behaviour in the team.

$\Delta^{L}_{H-L} \leq \Delta^{H}_{H-L} < 0$ means that self-interested behaviour is dominance strategy.

When $\beta\mu y - \frac{y^2}{2} - \Lambda xy + \frac{1}{2}\gamma < 0$ there is $s_2 = \frac{-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma}{\gamma} > 1$.So just consider two points $s_1 = 0$ and $s_3 = 1$, there are:

$$F'(0) = \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma < 0$$
$$F'(1) == -\beta\mu y + \frac{y^2}{2} + \Lambda xy - \frac{1}{2}\gamma > 0$$

So $s_1 = 0$ is the only evolutionary stabilisation strategy.

Conclusion 2: When $\beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma > 0$, i.e., $\Delta^{H}_{H-L} \geq \Delta^{L}_{H-L} > 0$, the evolution of the group will evolve into a stable strategy $s_3 = 1$, all team members choose to transfer knowledge to others.

$\Delta^{H}_{H-L} \geq \Delta^{L}_{H-L} > 0$ means that reciprocity behaviour is dominance strategy.

When $\beta\mu y - \frac{y^2}{2} - \Lambda xy > \frac{1}{2}\gamma$, there is $s_2 = \frac{-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma}{\gamma} < 0$. So just consider two points $s_1 = 0$ and $s_3 = 1$, there are:

$$F'(0) = \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma > 0$$
$$F'(1) == -\beta\mu y + \frac{y^2}{2} + \Lambda xy - \frac{1}{2}\gamma < 0$$

So $s_3 = 1$ is the only evolutionary stabilisation strategy.

Conclusion 3: when $-\frac{1}{2}\gamma \leq \beta\mu y - \frac{y^2}{2} - \Lambda xy \leq \frac{1}{2}\gamma$, i.e., $\Delta^{H}_{H-L} \geq 0$ and $\Delta^{L}_{H-L} \leq 0$, if the proportion of initial reciprocal actorss_0 is bigger than s_2, the evolution of the group will evolve into a stable strategy $s_3 = 1$, all team members choose to transfer knowledge to others. Otherwise, the evolution of the group will evolve into a stable strategy $s_1 = 0$, there will not exist knowledge transfer behaviour in the team.

When $-\frac{1}{2}\gamma \leq \beta\mu y - \frac{y^2}{2} - \Lambda xy \leq \frac{1}{2}\gamma$, $s_2 \in [0, 1]$ there is

$$F'(s_1) = \beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma < 0$$
$$F'(s_2) = \frac{\left(-\beta\mu y + \frac{y^2}{2} + \Lambda xy + \frac{1}{2}\gamma\right)\left(\beta\mu y - \frac{y^2}{2} - \Lambda xy + \frac{1}{2}\gamma\right)}{\gamma} > 0 \, .$$
$$F'(s_3) == -\beta\mu y + \frac{y^2}{2} + \Lambda xy - \frac{1}{2}\gamma < 0$$

So, $s_1 = 0$ and $s_3 = 1$ are two evolutionary stabilisation strategies. And s_2 is a threshold that changes the characteristics of the system evolution. If the proportion of initial reciprocal actors is s_2, the expected utility of reciprocal behaviour and self-interest are the same. But this possible equilibrium is not a stable evolutionary equilibrium. Because if there is a type of variation, the member who chooses the self-interested behaviour instead chooses the reciprocal behaviour, which will directly lead to the expected utility of reciprocal behaviour is greater than self-interested behaviour. Thus the proportion of reciprocal actors continues to increase, and finally the self-interest has completely disappeared. So this equilibrium is unstable.

In this case, if only a small part of the team members (less than s_2) in the game select to transfer knowledge to others at the beginning, with innovation sustaining, stable strategy game results will finally evolve to the members of the team refused to transfer to his knowledge, that is, team spirit and the efficiency of knowledge innovation the team will be seriously affected. But if a large part of the team members (more than s_2) in the game select to transfer knowledge to others at the beginning, with innovation sustaining, stable strategy game results will finally evolve to all the members will take the initiative to carry out knowledge transfer to others, that is $s_3 = 1$.

The cause of these results is that members can not accurately grasp the game revenue. They compared the result of the game with the team's average income to determine the next action. When reciprocity members' profits are below the average income, they will choose self-interest in the next round. There will be no knowledge transfer in the team. At the same time, the existence of reciprocal preferences exacerbated this behaviour, because their utility is compromised, that is the reciprocal members did not get paid reciprocity in return. The 'ingratitude' behaviour will hit the enthusiasm of reciprocal behaviour, and refused to pay a mutual benefit to others. On the contrary, if the reciprocity members' profits are over the average income, they will choose reciprocal behaviour in the next round. The result of evolution is that all members actively transfer knowledge to others, and give full play to the team's ability to cooperate and innovate.

5. Simulation

We uses Matlab to simulate the evolution equilibrium strategy of the model with different parameter changes.

5.1. Influence of the proportion of initial reciprocal actors s_0

1. When $\beta\mu y - \frac{y^2}{2} - \Lambda xy + \frac{1}{2}\gamma < 0$, i.e.,$\Delta^L_{H-L} \le \Delta^H_{H-L} < 0$, suppose $\gamma = 1, \beta = 0.1, \mu = 0.1, y = 1, \Lambda = 0.1, x = 1$. When the proportion of initial reciprocal actors in the team is 0.2, 0.4, 0.7, 0.9 respectively, the simulation results are shown in Figure 1. Regardless of the value of s_0, as the number of steps in the evolutionary iteration increases, fewer and fewer members choose reciprocal behaviour in the team, and finally stabilise to 0. That is, no one is willing to transfer knowledge to others, and there is no knowledge flow and sharing within the team. At the same time, we can see that as s_0 increases, more steps required to implement an evolutionary stabilisation strategy $s_1 = 0$, the longer it takes.
2. when $\beta\mu y - \frac{y^2}{2} - \Lambda xy - \frac{1}{2}\gamma > 0$, i.e.,$\Delta^H_{H-L} \ge \Delta^L_{H-L} > 0$, suppose $\gamma = 0.1, \beta = 0.1, \mu = 0.1, y = 1, \Lambda = 0.1, x = 1$. When the proportion of initial reciprocal actors in the team is 0.2, 0.4, 0.7, 0.9 respectively, the simulation results are shown in Figure 2. Regardless of the value of s_0, as the number of steps in the evolutionary iteration increases, more and more members choose reciprocal behaviour in the team, and finally stabilise to 1. That is, members are more willing to cooperate with others on a reciprocal basis and share our own knowledge. At the same time, we can see that as s_0 increases, fewer steps required to implement an evolutionary stabilisation strategy $s_3 = 1$, the shorter it takes.
3. when $-\frac{1}{2}\gamma < \beta\mu y - \frac{y^2}{2} - \Lambda xy < \frac{1}{2}\gamma$, i.e., $\Delta^H_{H-L} > 0$ and $\Delta^L_{H-L} < 0$, suppose $\gamma = 1, \beta = 0.2, \mu = 1, y = 0.1, \Lambda = 0.1, x = 1$. When the proportion of initial reciprocal actors in the team is 0.2, 0.4, 0.7, 0.9 respectively, the simulation results are shown in Figure 3. As s_o increases, evolutionary stable equilibrium changes from $s_1 = 0$ to $s_3 = 1$. That means an increase of the proportion of initial reciprocal actors contributes to the realisation of mutual benefit. At the same time, we can see that as s_0 increases, the more steps required to implement an evolutionary stabilisation strategy $s_1 = 0$, the longer it takes, while fewer steps required to implement an evolutionary stabilisation strategy $s_3 = 1$, the shorter it takes.

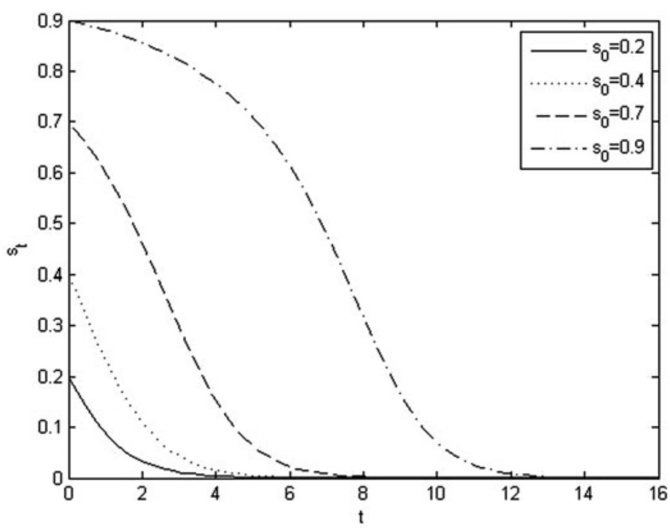

Figure 1. Simulation of s_0 changes when $\Delta^L_{H-L} \le \Delta^H_{H-L} < 0$.

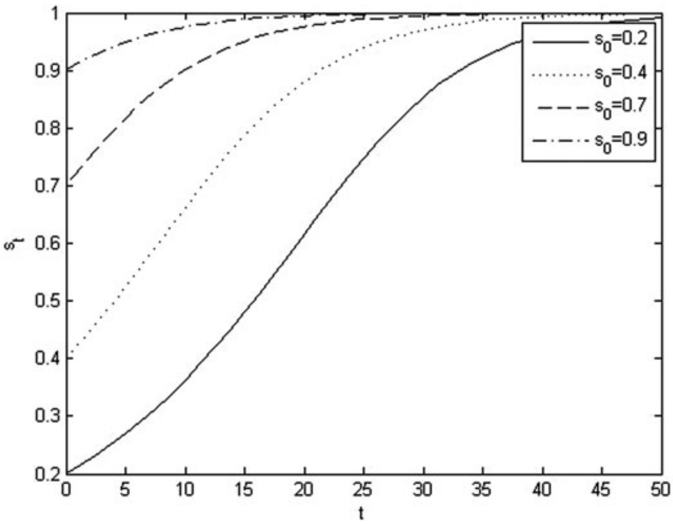

Figure 2. Simulation of s_0 changes when $\Delta^H_{H-L} \geq \Delta^L_{H-L} > 0$.

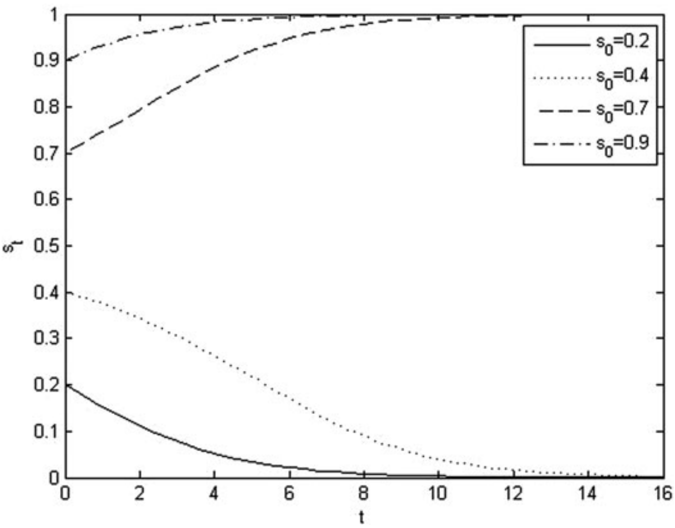

Figure 3. Simulation of s_0 changes when $\Delta^H_{H-L} > 0$ and $\Delta^L_{H-L} < 0$.

In summary, no matter what the final evolutionary stability is, the bigger the proportion of initial reciprocal actors is, the harder it is to achieve stable equilibrium $s_1 = 0$, the easier it is to achieve stable equilibrium $s_3 = 1$.

5.2. Influence of the reciprocal preference intensity γ

When $\gamma = 0$, $\Delta_{H-L} = \Delta^H_{H-L} = \Delta^L_{H-L} = \beta\mu y - \frac{y^2}{2} - \Lambda xy$ means the material spreads in reciprocity and self-interested behaviour.

1. When $\Delta_{H-L} < 0$, γ has a positive impact on the evolution results
   First, the existence of γ can make up for the spreads in the reciprocal income

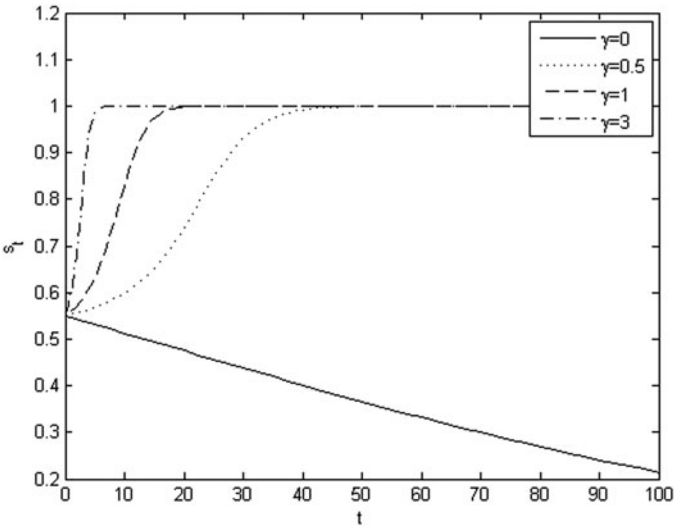

Figure 4. Simulation of γ changes when $\Delta_{H-L}<0$.

and the self-interested income, so that $\Delta^{H}_{H-L}>0$ may appear, avoiding the absolute of evolution to $s_1=0$. Second, the bigger γ is, the smaller s_2 is ($\frac{\partial s_2}{\partial \gamma}=\frac{\beta\mu y-\frac{y^2}{2}-\Lambda xy}{\gamma^2}<0$, when $\beta\mu y-\frac{y^2}{2}-\Lambda xy<0$), and the easier stable equilibrium $s_3=1$ can be achieved.

Suppose $\beta=0.1, \mu=1, y=0.1, \Lambda=0.2, x=1, s_0=0.55$, when the members' reciprocal preference intensity γ is 0, 0.5, 1, 3 respectively, the simulation results are shown in Figure 4. As γ increases, evolutionary stable equilibrium changes from $s_1=0$ to $s_3=1$, and fewer steps required to implement an evolutionary stabilisation strategy, the shorter it takes.

2. When $\Delta_{H-L}>0$, γ has a negative impact on the evolution results

First, the existence of γ put forward higher requirements for spreads in reciprocity and self-interested behaviour. Only when $\Delta^{L}_{H-L}=\beta\mu y-\frac{y^2}{2}-\Lambda xy-\frac{1}{2}\gamma>0$, stable equilibrium $s_1=0$ will not appear. Second, the bigger γ is, the bigger s_2 is ($\frac{\partial s_2}{\partial \gamma}=\frac{\beta\mu y-\frac{y^2}{2}-\Lambda xy}{\gamma^2}>0$, when $\beta\mu y-\frac{y^2}{2}-\Lambda xy>0$), and the harder stable equilibrium $s_3=1$ can be achieved.

Suppose $\beta=0.2, \mu=1, y=0.1, \Lambda=0.1, x=1, s_0=0.45$, when the members' reciprocal preference intensity γ is 0, 0.5, 1, 3 respectively, the simulation results are shown in Figure 5. As γ increases, evolutionary stable equilibrium changes from $s_3=1$ to $s_1=0$, and fewer steps required to implement an evolutionary stabilisation strategy, the shorter it takes.

5.3. Influence of other parameters

1. Influence of the proportion of sharing β

Suppose $\gamma=1, \mu=1, y=0.1, \Lambda=0.1, x=1, s_0=0.5$, When the proportion of sharing β is 0.05, 0.1, 0.2, 0.3 respectively, the simulation results are shown in Figure 6. As β increases, evolutionary stable equilibrium changes from $s_1=0$ to

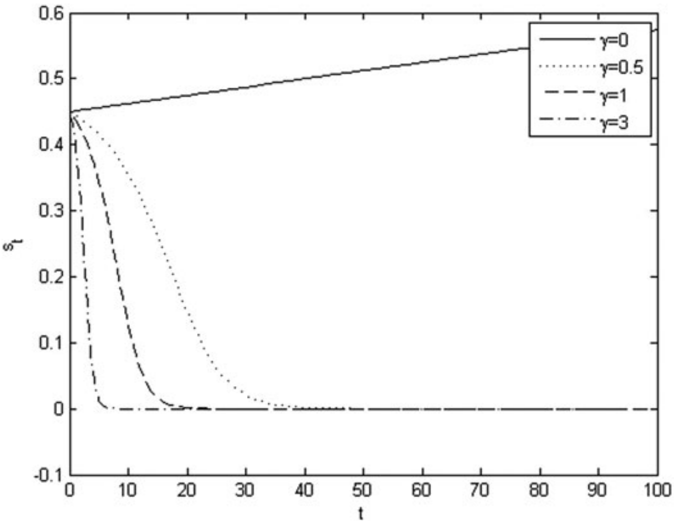

Figure 5. Simulation of γ changes when $\Delta_{H-L}>0$.

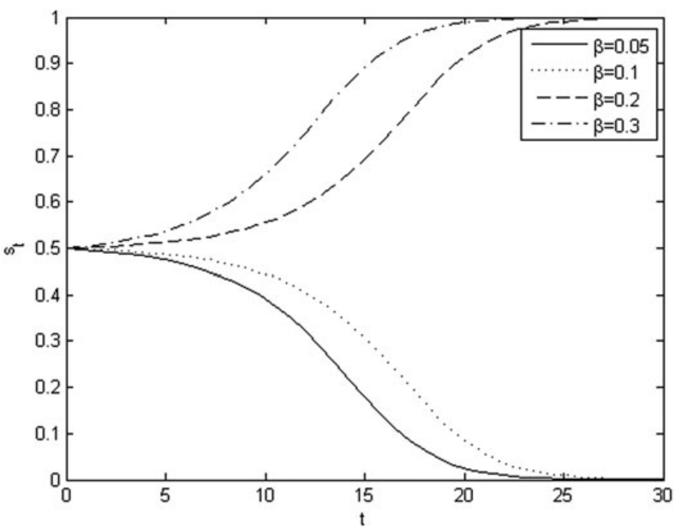

Figure 6. Simulation of β changes.

$s_3 = 1$. So we consider that β has a positive impact on the evolution results. The reason for this is that as β increases, the total team output can increase the income of the members more significantly, and increase spreads in reciprocity and self-interested behaviour. Only when the reciprocal benefit is larger than the self-interest benefit, the stable equilibrium $s_3 = 1$ is possible. Besides, the bigger β is, the smaller s_2 is $(\frac{\partial s_2}{\partial \beta} = \frac{-\mu y}{\gamma} < 0)$, and the easier stable equilibrium $s_3 = 1$ can be achieved.

2. Influence of the degree of knowledge complementation μ

Suppose $\gamma = 1, \beta = 0.2, y = 0.1, \Lambda = 0.1, x = 1, s_0 = 0.5$, when the degree of knowledge complementation μ is 0.1, 0.3, 0.6, 1 respectively, the simulation

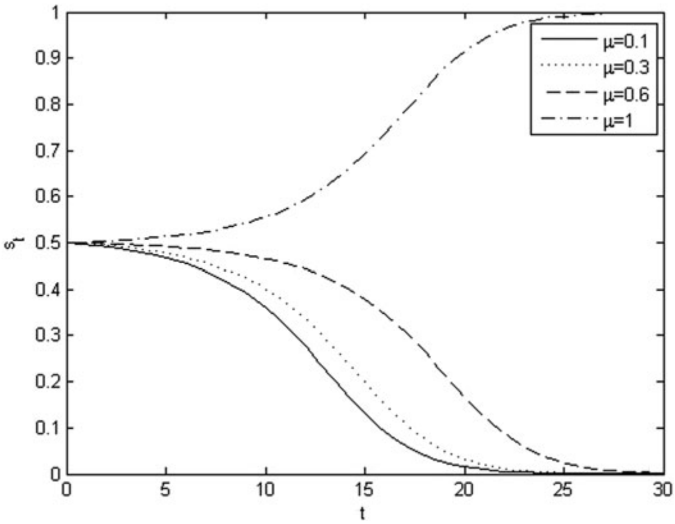

Figure 7. Simulation of μ changes.

results are shown in Figure 7. As μ increases, evolutionary stable equilibrium changes from $s_1 = 0$ to $s_3 = 1$. So we consider that μ has a positive impact on the evolution results.

The reason for this is that as μ increases, the contribution of knowledge transfer behaviour to individual output and thus to the total output of the team becomes greater, and increase spreads in reciprocity and self-interested behaviour. Only when the reciprocal benefit is larger than the self-interest benefit, the stable equilibrium $s_3 = 1$ is possible. Besides, the bigger μ is, the smaller s_2 is ($\frac{\partial s_2}{\partial \mu} = \frac{-\beta y}{\gamma} < 0$), and the easier stable equilibrium $s_3 = 1$ can be achieved.

3. Influence of the work conflict Λ

   Suppose $\gamma = 1, \beta = 0.2, \mu = 1, y = 0.1, x = 1, s_0 = 0.5$, when the conflict coefficient between individual work efforts and knowledge transfer efforts. Λ is 0.1, 0.2, 0.4, 0.5 respectively, the simulation results are shown in Figure 8. As Λ increases, evolutionary stable equilibrium changes from $s_3 = 1$ to $s_1 = 0$.So we consider that Λ has a positive impact on the evolution results.

   As Λ increases, team members have to pay more for knowledge transfer to others, spreads in reciprocity and self-interested behaviour reduce obviously. And the bigger Λ is, the larger s_2 is ($\frac{\partial s_2}{\partial \Lambda} = \frac{xy}{\gamma} > 0$), and the harder stable equilibrium $s_3 = 1$ can be achieved.

6. Revelation

Based on the previous evolutionary game analysis and simulation results, we propose the following suggestions on how to promote knowledge transfer behaviour to improve team innovation performance.

1. According to the results of 5.1, the greater the proportion of initial reciprocal actors s_0, the more favourable to the realisation of the stable strategy of $s_3 = 1$,

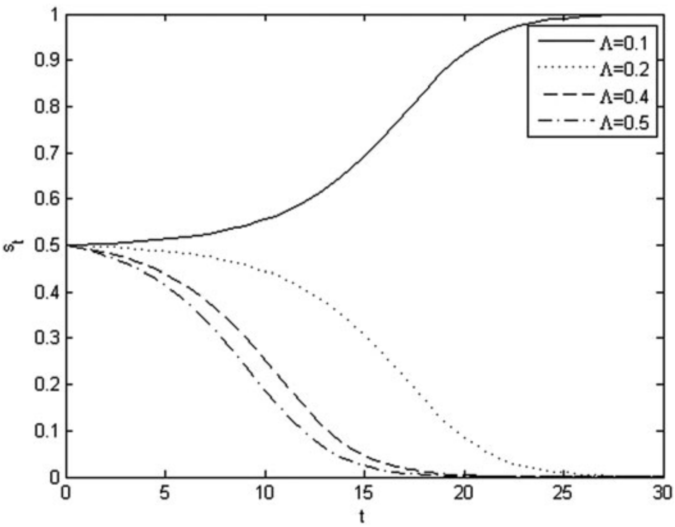

Figure 8. Simulation of Λ changes.

then in the daily management of the innovation team, some measures can be taken to guide the reciprocal behaviour of team members. First, we can encourage members who actively exchange knowledge and help each other with other people, such as issuing additional cooperation bonuses and awarding honorary titles, etc., encouraging everyone to carry out extensive knowledge transfer and achieve win-win cooperation; The two is to make use of people's Constable psychology, create a public opinion atmosphere of 'most people will cooperate with each other' within the team, and make some members who do not intend to transfer knowledge to others, think that since most people are willing to do this, they must have their reasons, and then follow most people to choose knowledge transfer; Third, to shape the mainstream values of the team that wins the cooperation, because the mainstream values of the team will affect the behaviour of each person in the team, which is why most successful companies attach great importance to their corporate culture. When mainstream values are deeply rooted in the hearts of the team members, more team members will actively choose reciprocal behaviour.

2. According to the result of 5.2, the reciprocal preference of team members γ is variable to knowledge transfer behaviour. As a result, the team managers should identify the reciprocal preferences of the members and select the most appropriate members according to the benefits of the innovation activities. Specifically, if the material benefits of team members' reciprocal behaviour are lower than self-interested behaviour, then members with strong reciprocal preferences should be selected when establishing an innovation team, because in the case, the reciprocal preference is helpful to realise Pareto optimality. If the material benefits of team members' reciprocal behaviour are higher than self-interested behaviour, then members with weaker reciprocal preferences should be selected When establishing an innovation team, because in this case, reciprocal preference is not helpful to realise Pareto optimality.

3. According to the results of 5.3, the increase of the proportion of the project output (β) contributes to realising Pareto optimality, so the team manager can consider increasing the proportion of members in a moderate range and making them more sharing the benefits of collective output, but limited by the total output and the number of team members, β can only be changed within a certain range, and the promotion effect of Pareto optimality realisation has limitations. The improvement of the knowledge complimentarily coefficient (μ) also contributes to the realisation of Pareto optimality. When establishing an innovation team and selecting team members, we should fully consider the knowledge structure of team members, form a complementary and complete knowledge system, and improve the efficiency of innovation. The conflict coefficient (Λ) between knowledge transfer effort and work effort is not conducive to realising Pareto optimality. Therefore, within the innovation team, smooth knowledge communication channels and an open knowledge innovation platform should be established to reduce the resistance flow of knowledge within the team.

Disclosure statement

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References

Changping, H., & Li, W. (2015). User relationship in virtual knowledge community and its influence on knowledge sharing behavior. *Information Studies: Theory & Application*, *38*(6), 71–76.

Chesbrough, H. (2011). *Open services innovation*. San Francisco, CA: Jossey-Bass. doi:10.1093/sw/24.2.168

Chunchun, H., Congying, Z., & Ye-An, Z. (2015). On the social preferences and social cooperation under risky conditions. *Academic Research*, *4*, 78–84.

Geanakoplos, J., Pearce, D., & Stacchetti, E. (1989). Psychological games and sequential rationality. *Games & Economic Behavior*, *1*(1), 60–79.

Guo, C., Ershi, Q., & Liang, L. (2015). Dynamic game analysis on knowledge sharing between enterprises considering enterprises' risk attitudes. *Science of Science and Management of S. & T*, *36*(6), 46–55.

Guodong, W., & Yongjian, P. (2011). Employee screening and selection: Incentive contract research based on Rabin fairness function under the condition that preference is hidden. *Journal of Industrial Engineering/Engineering Management*, *03*, 78–84.

Haixin, L., & Renjing, L. (2014). Research on the influencing factors of individual knowledge contribution behavior in firm-hosted virtual community. *Science Research Management*, *35*(6), 121–128.

Hejiang, G. (2014). Research on reciprocal and self-interested enterprise culture affecting innovation performance from a perspective knowledge acquisition. *Science & Technology Progress and Policy*, *31*(13), 135–140.

Kretschmer, T., & Puranam, P. (2008). Integration through incentives within differentiated organizations. *Organization Science*, *19*(6), 860–875. doi:10.1287/orsc.1070.0352

Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science*, *5*(1), 14–37. doi:10.1287/orsc.5.1.14

Rabin, M. (1993). Incorporating fairness into game theory and economics. *The American Economic Review*, *83*(5), 1281–1302.

Tongjian, Z. (2010). The research on the relativity among reciprocal preference, knowledge transfer and core competence cultivation. *R&D Management*, *22*(4), 47–52.

Tongjian, Z., & Yongjian, P. (2010). The relativity among reciprocal preference, tacit knowledge transition and technology innovation capability-based on the data test of R&D team. *Management Review*, *22*(10), 100–106.

Weidong, L., & Hong, L. (2014). An empirical study on relationship of mutual trust and R&D professionals' knowledge sharing intentions: The mediating effects of knowledge power loss and reciprocity. *Management Review*, *26*(3), 128–138.

Yean, Z., & Zifeng, S. (2008). The voluntary contribution mechanism of public goods: An experimental. *Research Economic Research Journal*, *8*, 90–104.

Zhimin, Z., Jiangle, Z., & Yiping, X. (2014). How do introversion-extraversion personality traits influence knowledge sharing behavior in online brand communities: The mediation of network centrality and reciprocity norm. *Nankai Business Review*, *17*(3), 19–29.