Effects of Innovation Efficiency and Knowledge on Industry-University Collaboration: An evolutionary Game perspective

Yang Song， Zhiyuan Zhang

Abstract

This paper studies the "evolutionarily stable strategy" (ESS) between industry and university during collaborative innovation process based on evolutionary game. By designing knowledge sharing models, we analyze the impact factors of knowledge input, knowledge transfer and innovation cost on collaborative innovation. Furthermore, we use simulation to verify the knowledge sharing model. Our results suggest that the "open innovation strategy" is actually the fact that players choose "evolutionarily stable strategy" in the long term collaborative innovation process. When the number of game players is different, the part with small number will reach the stabilization strategy. When the number of game players is the close, both game side adopting the "open strategy" at the same speed. Besides, we also suggest increasing knowledge spillover will contribute to innovation efficiency and stabilization. Theoretically, our study explains the stabilization strategy of the game and provides reasonable recommendations for policy makers.

Keywords

Collaborative Innovation, Knowledge input, Knowledge transfer, evolutionary game, evolutionarily stable strategy

1. Introduction

The collaboration between university and industries have always become the main concern for innovation in many countries. For developing countries such as China it is very important to promote the university-industry collaboration. The dynamics of the collaboration is influenced by many factors such as technology upgrading (Eichengreen, 2004; Etzkowitz and Leydesdorff, 2000; Nelson and Rosenberg, 1993)., knowledge sharing (Mansor et al., 2015; De Silva, M.,2018). Universities are considered as the base of knowledge (Asheim et al., 2011; Conceição and Heitor, 1999; Cooke et al., 1997; Guerrero et al., 2016; Mazzoleni and Nelson, 2007). We can not ignore the role of universities for regional development or innovation (Asheim et al., 2011; Conceição and Heitor,1999; Cooke et al., 1997; Guerrero et al., 2016; Mazzoleni and Nelson,2007). Therefore, in this paper, we would like to explore the collaboration between university and industry. In particular, we would like to discuss how to promote the collaboration from university side.

Of all the work mentioned in previous studies, knowledge sharing and resource exchange are still very important for the output and performance of the collaborative alliance (Al-Ashaab et al., 2011; Lee et al., 2012; Rigby and Edler, 2005). Evolutionary game theory has been considered as one of the tool to analyze the collaboration behaviors by researchers and scholars (e.g., Nowak, Sigmund 1989; Calvert 1995; Lindgren 1997; Watts 1999, Ch. 8; Jun, Sethi 2007; Kendall et al. 2007; Elsner, Heinrich 2009;

Berninghaus et al. 2013; Charness, Yang 2014; Marco, Goetz 2017; Zeng et al. 2017).During the evolution of game, the players learn from each other, which will influence their future behaviors. Therefore, we use evolution game model to study how university and industry can reach a relatively stable collaboration status.

Given that previous research only focus on the collaborative behaviors among industries. This paper will analyze the collaborative innovation process between industry and university. Based on the assumption of bounded rationality, we examine the evolution of the game between two players through knowledge sharing and knowledge spillover effects. Our paper will provide a logical explanation for the mechanism of collaborative innovation behavior.

2. The collaborative innovation game model between industry and university

2.1 Variables and Hypothesis

Currently, due to scientific and technological progress, the competition in the market is increasingly fierce. In order to survive in the market, industries need to maintain sustainable innovation capability. While technological progress is getting more difficult, complex and uncertain but stronger integration, industries are unable to cope with various challenges based on independent innovation. Therefore, collaborative innovation has been recognized by both industries and scholars.

Collaboration between industry, university is not only an important means to enhance the innovation ability of industries, but also an effective form to promote the combination of science, technology and economics. Industry, university are regarded as the two main subjects of knowledge creation and spillovers by endogenous growth theory (Romer, 1994). However, the industry-university collaboration hasn't achieved desired results yet because of low transformation rate of scientific research achievement, weak collaboration willingness, unreasonable collaboration model etc. To a large extent, whether the industry-university collaboration can achieve the desired goal depends on many factors such as the rationality of the players, the collaboration attitude, the expected output of the collaboration as well as the available resources. These factors lead to the instability of the collaborative innovation process between industry and university. On the one hand, due to the existence of asymmetric information, the "moral hazard" and "adverse selection" between industry and university, the players of the collaboration alliance share interests, however, the interests are not exactly the same, this will result in repeated games between players. On the other hand, the bounded rationality of the participant makes it difficult to find the optimal strategy quickly when facing complex problems. In other words, the process of collaboration is constantly changing and adjusting. The bounded rationality leads to the uncertainty of individual innovation behavior. Therefore, in order to further explain the internal mechanism of industry-university collaboration, based on previous research, we propose the following assumptions:

In accordance with previous studies, we start from the following assumptions:

Assumption 1： In the economic society there are two agents: industry and university. We indicate the player one from the industry group as E . We indicate player two from the university group as U .

Assumption 2: For both industry and universities, they have two strategies for innovation: {*Open Innovation, Closed Innovation*}. If both players choose the "*open innovation*" strategy, they can form a collaborative innovation alliance, if one player choose "*closed innovation*" strategy, they can not form a collaborative innovation alliance.

Assumption 3: The "industry" and "universities" do have a limited rationality due to the information asymmetry: In a sequentially repeated game, they do not necessarily know exactly, what strategy the other player will take. But they have some *learning capabilities*. Each type of agent has its own set of behavioral choices and resulting benefits (payoff structure).

Assumption 4: The game players are different in terms of innovation capability, knowledge input and output etc.

2.2 Evolutionary Game Model Construction

In order to design our model, we adopted the model from d'Aspremont and Jacquemin (1988), which suggested large enough technology spill rate can encourage business collaboration innovation. For the game player one- *industry* E and player two-*university* U share the same *innovation return function* π :

$$\pi = AK^{\alpha} - rK^2 \tag{1}$$

In this function, $A > 0$, $0 < a < 1$, π is the *innovation return*. K is *knowledge input* (such as patent, R & D et al); A is *innovation efficiency*, which is the industrial profits formed by knowledge input during innovation process. α is the *output elasticity* of knowledge input (such as patent conversion rate, etc). Given that industry and university have different innovation capabilities, they have different innovation input, knowledge input and knowledge output etc. We specify innovation efficiency of industry as A_E . The knowledge input is K_E . The output elasticity of knowledge input is α_E . The innovation efficiency of university is A_U . The knowledge input is K_U .The output elasticity of knowledge input is α_U . If the industry and the university form a knowledge sharing collaborative innovation alliance, the knowledge input is:

$$\tilde{K} = [(K_E)^{\rho} + (K_U)^{\rho}]^{1/\rho} \tag{2}$$

ρ is the degree of complementarity of knowledge in the collaborative innovation alliance, and $0 < \rho \leq 1$. A lower value of ρ implies a higher degree of complementarity. The existing literature assumes perfect substitutability by setting ρ equal to 1 so that the marginal productivity of R&D investment of each firm is always independent of the investment made by the other firm (Kamien et al.,1992; Anbarci,2002). We define β , $\beta \in (0,1)$ as the knowledge spillover coefficient in order to reflect the transfer and absorption of knowledge among players in the collaborative innovation alliance. Based on our assumption 2, the players have two strategies to choose {open innovation, closed innovation}, there are two types of combinations for the participants mode.

2.2.1 The industry group and the university choose different innovation strategy

When "industry" chooses ***open innovation*** strategy, "university" chooses ***closed innovation*** strategy. The "industry" will invest all the *knowledge* K_E into collaborative innovation alliance. The *knowledge spillover coefficient* is β . The "university" will get the knowledge input from the industry: βK_E . As the university chooses *closed innovation* strategy, the industry won't get the knowledge input from the university. The *knowledge transfer* from industry to university is βK_E which can lower the research cost of the university to $r_{EU}\beta K_E$. The additional cost of industry caused by knowledge spillover is C_E. Thus, the *payoff* function of industry is π_{12}^E, the payoff function of the university is π_{12}^U:

$$\pi_{12}^E = A_E K_E^{\alpha_E} - rK_E^2 - C_E \tag{3}$$

$$\pi_{12}^U = A_U[\beta K_E^\rho + K_U^\rho]^{\alpha_U/\rho} - rK_U^2 + r_{EU}\beta K_E \tag{4}$$

When chooses ***closed innovation*** strategy, "university" chooses ***open innovation*** strategy. The "university" will invest all the *knowledge* K_U into collaborative innovation alliance. The knowledge spillover coefficient is β. The industry will get the knowledge input from the university: βK_U. As the "industry" chooses closed innovation strategy. The "university" won't get the knowledge input from industry. The knowledge transfer from university to industry is βK_U which can lower the research cost of the industry to $r_{UE}\beta K_U$. The additional cost of university caused by knowledge spillover is C_U. Thus, the *payoff* function of the industry is π_{21}^E, the payoff function of the university is π_{21}^U:

$$\pi_{21}^E = A_E[K_E^\rho + \beta K_U^\rho]^{\alpha_E/\rho} - rK_E^2 + r_{UE}\beta K_U \tag{5}$$

$$\pi_{21}^U = A_U K_U^{\alpha_U} - rK_U^2 - C_U \tag{6}$$

2.2.2 The industry group and the university group choose same innovation strategy.

When both industry and university choose ***open innovation*** strategy, the two players trust each other in the collaborative innovation alliance. The "industry" will invest all the *knowledge* K_E into collaborative innovation alliance. The "university" will invest all the knowledge K_U into collaborative innovation alliance. Both sides could obtain all the *knowledge input* from the other player. The *knowledge transfer* from university to industry is K_U which can lower the research cost of the industry to $r_{UE}K_U$. The knowledge transfer from industry to university is K_E which can lower the research cost of the university to $r_{EU}K_E$. Therefore, we have the *payoff* function π_{11}^E for the "industry" and the *payoff* function π_{11}^U for the "university":

$$\pi_{11}^E = A_E[K_E^\rho + K_U^\rho]^{\alpha_E/\rho} - rK_E^2 + r_{UE}K_U \tag{7}$$

$$\pi_{11}^U = A_U[K_E^\rho + K_U^\rho]^{\alpha_U/\rho} - rK_U^2 + r_{EU}K_E \tag{8}$$

When both industry and university choose ***closed innovation*** strategy In this case, although they may form an innovation alliance, they don't trust each other. However, they have to invest their knowledge into the innovation alliance to conduct independent innovation activities. Therefore, we have the *payoff* function π_{22}^E for the "industry" and the *payoff* function π_{22}^U for the "university":

$$\pi_{22}^E = A_E K_E^{\alpha_E} - rK_E^2 \tag{9}$$

$$\pi_{22}^U = A_U K_U^{\alpha_U} - rK_U^2 \tag{10}$$

Based on the above mentioned cases, we have the *payoff matrices* for industry and university of an innovation alliance (Table 1)

Table 1 *Payoff matrix* for industry and university in the innovation alliance

		The university group	
		Open innovation: y	Closed innovation: $1-y$
Industry group	Open innovation: x	π_{11}^E; π_{11}^U	π_{12}^E; π_{12}^U
	Closed innovation: $1-x$	π_{21}^E; π_{21}^U	π_{22}^E; π_{22}^U

3. Construction and Analysis of Game Model

3.1 Solution to the Game Model

Assume at time t, if the ratio of *open innovation strategy* of the industry is $x(t)$, $x(t) \in [0,1]$, then the ratio of *closed innovation strategy* of the industry is $1-x(t)$. If the ratio of *open innovation strategy* of the university is $y(t)$, $y(t) \in [0,1]$. Then the ration of *closed innovation strategy* of the university is $1-y(t)$. Given the current period $x(t)$, the next phase to take open innovation and closed innovation strategies for the industry are:

$$u_H = y(t)\pi_{11}^1 + (1-y(t))\pi_{12}^1 \tag{11}$$

$$u_B = y(t)\pi_{21}^1 + (1-y(t))\pi_{22}^1 \tag{12}$$

Therefore, the average payoff of the industry group is:

$$\bar{u} = x(t)u_H + (1-x(t))u_B \tag{13}$$

We define the current period as $y(t)$, when adopting open innovation strategy and closed innovation strategy, the expected payoff of the next period for the university are:

$$v_H = x(t)\pi_{11}^2 + (1-x(t))\pi_{21}^2 \tag{14}$$

$$v_B = x(t)\pi_{12}^2 + (1-x(t))\pi_{22}^2 \tag{15}$$

Therefore, the average payoff for the university is:

$$\bar{v} = y(t)v_H + (1-y(t))v_B \tag{16}$$

When mentioning the dynamic change speed of $x(t)$ and $y(t)$, we adopted the dynamic equations from previous study (Amann & Possajennikov, 2009):

$$F(x) = dx/dt = x(1-x)(y(\pi_{11}^E - \pi_{21}^E) + (1-y)(\pi_{12}^E - \pi_{22}^E)) \tag{17}$$

We define $F(x)=0$, and get: $x_1^* = 0$, $x_2^* = 1$, $y^* = (\pi_{12}^E - \pi_{22}^E)/[(\pi_{12}^E - \pi_{22}^E) - (\pi_{11}^E - \pi_{21}^E)]$

Similarly, we have the dynamic equation for university group:

$$F(y) = dy/dt = y(1-y)(x(\pi_{11}^U - \pi_{12}^U) + (1-x)(\pi_{21}^U - \pi_{22}^U)) \tag{18}$$

We define $F(y)=0$, and get: $y_1^* = 0$, $y_2^* = 1$, $x^* = (\pi_{21}^U - \pi_{22}^U)/[(\pi_{21}^U - \pi_{22}^U) - (\pi_{11}^U - \pi_{12}^U)]$

We combine equation (17) and (18), take industry and university as a system, the system has five special dynamic system balance points, which are (0, 0)、(0, 1)、(1, 0)、(1, 1) and (x^*, y^*).According to the local stability of the Jacobi matrix, the local stability of the system in these dynamic systems is analyzed. Using the equations (17) and (18), we can calculate the sign and trace of the matrix determinant at the equilibrium point ($x=0$, $y=0$):

The determinant of J is: $(\pi_{12}^E - \pi_{22}^E)(\pi_{21}^U - \pi_{22}^U) > 0$ (19)

The trace of J is: $(\pi_{12}^E - \pi_{22}^E) + (\pi_{21}^U - \pi_{22}^U) < 0$ (20)

Similarly, we can calculate the other four dynamic system balance points: ($x=1$, $y=0$)、($x=0$, $y=1$)、($x=1$, $y=1$) and ($x=x^*$, $y=y^*$) as well as the signs of determinants and trace, thus we have the results of evolutionarily stable strategy (Table 2).

Table 2 Results of evolutionarily stable strategy

Equilibrium point	The sign of	The sign of	Result

	determinant of J	trace of J	
$x=0$; $y=0$	+	−	*ESS*
$x=1$; $y=0$	+	+	Unstable point
$x=0$; $y=1$	+	+	Unstable point
$x=1$; $y=1$	+	−	*ESS*
$x^*=(\pi_{21}^U-\pi_{22}^U)/[(\pi_{21}^U-\pi_{22}^U)-(\pi_{11}^U-\pi_{12}^U)]$ $y^*=(\pi_{12}^E-\pi_{22}^E)/[(\pi_{12}^E-\pi_{22}^E)-(\pi_{11}^E-\pi_{21}^E)]$	0	0	Saddle point

According to the results of evolutionarily stable strategy among industry and university (Figure 1), we can have the phase diagram of the evolutionary process. As seen in Figure 1, considering the effect of *knowledge input, knowledge transfer, innovation costs* and other factors on the game among the collaborative innovation alliance, (1,1) and (0,0) are the evolutionarily stable strategy points of the evolutionary game system. The four regions of the system have different convergence states, in area i the system converges to (0,0). The evolutionarily stable strategy is (closed innovation, closed innovation). From the game payoff function, we can see that the strategy of both players (closed innovation, closed innovation) is a typical "prisoner's dilemma" phenomenon. In area iii the system converges to (1,1). The evolutionarily stable strategy is (open innovation, open innovation). In region ii, the direction of evolution of the system can not be determined, in the triangle region y^*ZG, the evolution will enter into region i. The evolutionarily stable strategy is (closed innovation, closed innovation). Other region will enter into region iii and converges to (1,1). The evolutionarily stable strategy is (open innovation, open innovation). The direction of region can not be determined as well. The triangle region x^*GH will enter region i and converges to (0,0). The evolutionarily stable strategy is (closed innovation, closed innovation). Other region will enter into region iii and converges to (1,1). The evolutionarily stable strategy is (open innovation, open innovation). According to Figure 1, G is the Saddle point, which represents that the industries choose open innovation strategy with the probability of x^*, while the universities choose open innovation strategy with the probability of y^*. Both game players stay unchanged strategy until the other side change its strategy. The system enters to one of the four regions and converges to the evolutionarily stable strategy points. The purpose is to make the system more likely to converge to (1,1), therefore, we hope to increase the area of the region iii as much as possible and decrease the triangle region y^*ZG , x^*GH and region i.

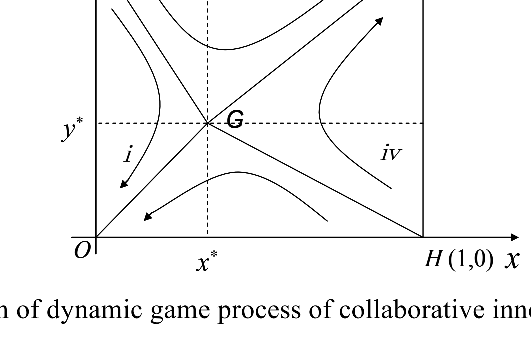


Figure 1 The phase diagram of dynamic game process of collaborative innovation alliance evolution

3.2 Influential Factors of Strategy Choice of Industries and Universities

Based on above mentioned and a dual perspective of industry and university, we take the premise that both parties have limited rationality. When we discuss the strategic choice of industries and universities in the game, the evolutionarily stable strategy is (open innovation, open innovation) and (closed innovation, closed innovation). However, we can not say which is the case of Pareto optimality (Pardalos, P. M., Migdalas, A., & Pitsoulis, L., 2008.). It can be seen from Figure 1 that the direction in which the equilibrium result evolves is more likely to be determined by the area of quadrilateral area S_{OZGH} and the area of quadrilateral area S_{MZGH}. If $S_{OZGH} < S_{MZGH}$, the probabilities which industry and university evolve to the direction of choosing *open innovation* strategy are smaller than choosing *closed innovation* strategy. If $S_{OZGH} > S_{MZGH}$, the probabilities which industry and university evolve to the direction of choosing *open innovation* strategy are bigger than choosing *closed innovation* strategy. If $S_{OZGH} = S_{MZGH}$, the probabilities which industry and university evolve to the direction of choosing *open innovation* strategy equal to the probabilities of choosing *closed innovation* strategy.

Therefore, according to Figure 1, the relationship between the size of S_{OZGH} and S_{MZGH} area directly determines the probability that the industry chooses *open innovation* strategy and the probability that the university chooses true disclosure strategy. As $S_{OZGH} + S_{MZGH} = 1$, we only need to discuss the size of S_{OZGH}. The area of S_{OZGH} can be decomposed into the area of triangle area S_{OZG} and the area of triangle area S_{OHG}. Therefore, the factors influencing the probabilities of both industry and university choosing *open innovation* strategy can be analyzed by the factors influencing the size of area S_{OZG} and area S_{OHG}. Similarly, the size of area S_{MZGH} determines the probability that industry chooses open innovation strategy. As $S_{OLGN} + S_{MLGN} = 1$, the influence of the same factor on the probability of the *open innovation* strategy chosen by industry and the probability of the *open innovation* strategy chosen by university have an inverse relationship. When analyzing the factors that affect the probability of industry choosing open innovation strategy and the factors that affect the size of university choosing open innovation strategy, we use our assumptions.

$$S_{OHG} = x_1^*/2 = (\pi_{21}^U - \pi_{22}^U)/[(\pi_{21}^U - \pi_{22}^U) - (\pi_{11}^U - \pi_{12}^U)]/2 \quad (21)$$

$$S_{OZG} = y_2^*/2 = (\pi_{12}^E - \pi_{22}^E)/[(\pi_{12}^E - \pi_{22}^E) - (\pi_{11}^E - \pi_{21}^E)]/2 \quad (22)$$

In order to intuitively see the effects of the parameters contained in Eqs. (21) and (22) on the path of evolution of strategy choices of both players, specifically, the influence of factors such as the amount of knowledge input, the level of knowledge spillover and the cost of innovation on the evolution path of industry and university strategy choices, Matlab 2014a software will be used as a numerical simulation tool to simulate the evolution path of strategy choice of both players.

4. Numerical simulation

We use MATLAB 2014a for the numerical simulation. We analyzed factors that affect the evolution path in the collaborative innovation alliance. We also analyzed the impact factors on the stability of collaborative innovation alliance. The numerical simulation can provide the insights about how the variables influences the evolution path and give extra evidence to the game model.

4.1 The Impact of Innovation Efficiency A

Given that the industry and the university have different innovation capabilities, they have different *knowledge input* and *knowledge output*. We assume the *innovation efficiency* of the industry A_E=0.5. The *knowledge input* K_E=3.The *output elasticity* of knowledge input α_E=1. The *knowledge spillover coefficient* $\beta=0.5$.The additional cost C_E=2. The *innovation efficiency* of the university A_U=0.5. The *knowledge input* K_U=2.The *output elasticity* of knowledge input α_U=1. The *additional cost* C_U=2. The *degree of complementarity of knowledge* $\rho=1$. The *knowledge input cost coefficient* r=0.5 . The industry *innovation cost reduction factor* r_{UE}=0.2. The university *innovation cost reduction factor* r_{EU}=0.2. Now we increase the innovation efficiency of industry from A_E=0.5 to A_E=1 and get Figure 1. We increase the innovation efficiency of university from A_U=0.5 to A_U=1 and get Figure 2.

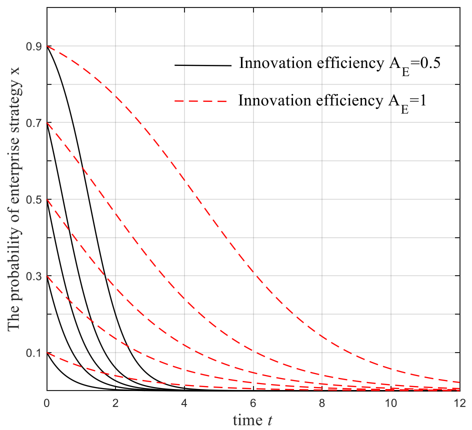


Figure 1 Increasing innovation efficiency on industry's evolutionary path

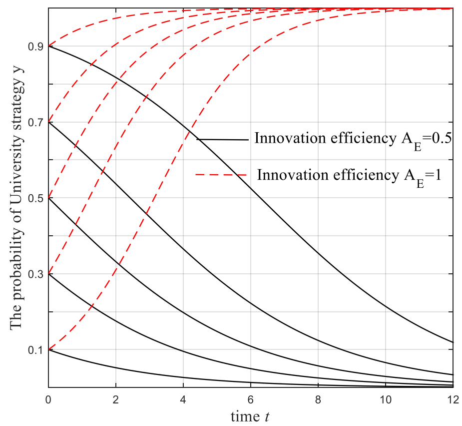


Figure 2 Increasing innovation efficiency on university's evolutionary path

As shown in Figure 1, the black solid evolution curve is the evolution path of the industry when innovation efficiency A_E=0.5. The five curves represent the probability that industry chooses open innovation strategy from $x(t)=0.1$ to $x(t)=0.9$ respectively. As for industry group, because of the low innovation efficiency, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards to the choice of closed innovation strategy. The red dotted evolution curve is the evolution path of the industry when innovation efficiency A_E=1. The five curves represent the probability of choosing open innovation strategy $x(t)=0.1$ to $x(t)=0.9$ respectively. As for industry group, because of the improvement of innovation efficiency, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards the choice of close innovation strategy. However, the evolutionary speed is obviously getting slower. Therefore, no matter what the probability of choosing open innovation strategy is, the industry group will evolve towards to closed innovation strategy.

As shown in Figure 2, the black solid evolution curve is the evolution path of the university when innovation efficiency A_U=0.5. The five curves represent the probability that university chooses open innovation strategy from $y(t)=0.1$ to $y(t)=0.9$ respectively. As for university group, because of the low innovation efficiency, regardless of the probability of initial choice of open innovation strategy, the final university group is evolving towards to the choice of closed innovation strategy. The red dotted evolution curve is the evolution path of the university when innovation efficiency A_E=1. The five curves represent the probability that university chooses open innovation strategy from $y(t) = 0.1$ to $y(t) = 0.9$ respectively. As for university group, because of the improvement of innovation efficiency, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards to the choice of open innovation strategy.

Through the comparative analysis of Figure 1 and Figure 2, when improving the efficiency of innovation, the industry group will still choose closed innovation strategy at a relatively slower evolving speed. However, the university will actively choose open innovation strategy. Meanwhile, the speed of evolving towards choosing open innovation strategy is significantly faster than evolving towards choosing closed innovation strategy.

As shown in Figure 1,when the innovation efficiency is relatively lower, when $t = 3$, the probability of choosing closed innovation strategy for the industry is almost stable to $x(t) = 0$. While when the innovation efficiency is relatively higher, when $t = 10$, the probability of choosing closed innovation strategy for the industry is almost stable to $x(t) = 0$.

As shown in Figure 2,when the innovation efficiency is relatively lower, after $t = 10$, the probability of choosing closed innovation strategy for the university is almost stable to $y(t) = 0$. While when the innovation efficiency is relatively higher, when $t = 8$, the probability of choosing open innovation strategy for the university is almost stable to $y(t) = 1$.

In other words, the university group can evolve and stabilize faster to the equilibrium point than the industry group. In addition, the university group is more likely to choose open innovation strategy. This is because the knowledge input and the cost of the industry is higher than the knowledge input of university. Therefore, as for the collaborative innovation alliance, the game side which invest lower knowledge input and cost is more willing to form the collaborative innovation alliance.

4.2 The Impact of the degree of complementarity of knowledge ρ on Collaborative Innovation Alliance

We keep most of the simulation parameters in 4.1. We define the innovation efficiency of industry A_E=0.5. The knowledge input K_E=3. The output elasticity of knowledge input α_E=1. The additional cost C_E=2. The innovation efficiency of university A_U=0.5. The knowledge input K_U=2. The output elasticity of knowledge input α_U=1. The additional cost C_U=2. The knowledge spillover coefficient $\beta = 0.5$. Now we change the degree of complementarity of knowledge from $\rho = 1$ to $\rho = 0.5$,we get the Figure 3 and Figure 4 to observe the evolutionary path of player one industry and player two university.

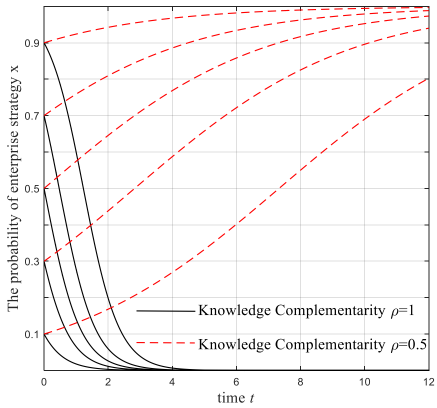


Figure 3

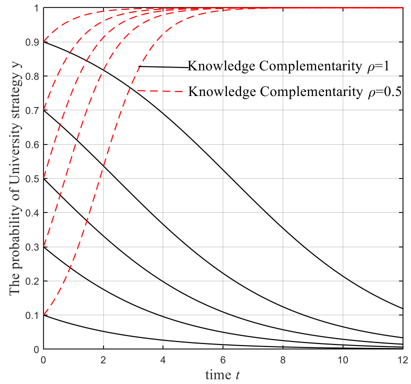


Figure 4

Figure 3 Complementarity of knowledge on industry's evolutionary path

Figure 4 Complementarity of knowledge on university's evolutionary path

As shown in Figure 3, the black solid evolution curve is the evolution path of the industry when the degree of complementarity of knowledge $\rho = 1$. The five curves represent the probability that industry chooses open innovation strategy is from $x(t) = 0.1$ to $x(t) = 0.9$ respectively. As for industry group, because of the higher degree of complementarity of knowledge, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards to the choice of closed innovation strategy. The red dotted evolution curve is the evolution path of the industry when degree of complementarity of knowledge $\rho = 0.5$. The five curves represent the probability of choosing open innovation strategy is from $x(t) = 0.1$ to $x(t) = 0.9$ respectively. As for industry group, because of the lower degree of complementarity of knowledge, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards the choice of open innovation strategy.

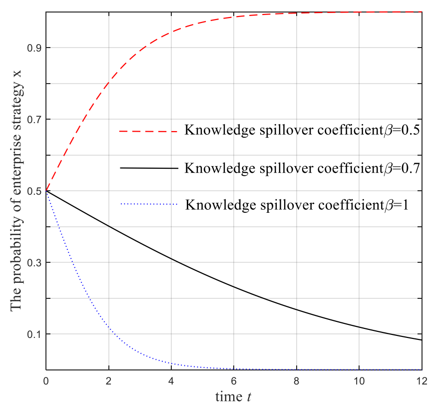
As shown in Figure 4, the black solid evolution curve is the evolution path of the university when the degree of complementarity of knowledge $\rho = 1$. The five curves represent the probability that the university chooses open innovation strategy is from $y(t) = 0.1$ to $y(t) = 0.9$ respectively. As for the university group, because of the higher degree of complementarity of knowledge, regardless of the probability of initial choice of open innovation strategy in the university group, the final university group is evolving towards to the choice of closed innovation strategy. The red dotted evolution curve is the evolution path of the university when degree of complementarity of knowledge $\rho = 0.5$. The five curves represent the probability of choosing open innovation strategy is from $y(t) = 0.1$ to $y(t) = 0.9$ respectively. As for the university group, because of the lower degree of complementarity of knowledge, regardless of the probability of initial choice of open innovation strategy in the university group, the final university group is evolving towards the choice of open innovation strategy.

Through the comparative analysis of Figure 3 and Figure 4, whether it is industry group or university group, when the degree of complementarity of knowledge is lower, both game sides will actively choose open innovation strategy. When the degree of complementarity of knowledge is higher, the speed that university evolves towards to choosing closed innovation strategy is significantly slower than that for the industry group. As shown in Figure 3,when $t=3$, the probability of choosing open innovation strategy for the industry is almost stable to $x(t)=0$. As shown in Figure 4, after $t=12$, the probability that university choose closed innovation strategy is nearly stable to $y(t)=0$.When the degree of complementarity of knowledge is relatively lower, the speed that university evolves towards to choosing open innovation strategy is significantly faster than that for the industry group. As shown in Figure 3, when $t=12$, the probability of choosing open innovation strategy for the industry is nearly stable to $x(t)=1$. As shown in Figure 4, when $t=6$, the probability of choosing open innovation strategy for the university is nearly stable to $y(t)=1$. This is because the industry group invests a large amount of knowledge and spends more on the cost, while the knowledge spillover has less effect on the cost reduction. Therefore, for collaborative innovation alliances, the less input knowledge, the more obvious the effect of knowledge spillover on cost reduction, the more it hopes to form a synergistic innovation alliance as soon as possible.

In addition, comparing Figure 1 and Figure 3, the evolution of industry groups to open innovation strategy is faster. Comparing Figure 2 and Figure 3, universities and research institutes have evolved faster toward cooperative innovation strategies. This shows that reducing the complementarity of knowledge is more effective than providing innovation efficiency to the formation of collaborative innovation alliances.

4.3 The Knowledge Spillover Coefficient β on Collaborative Innovation Alliance

We keep most of the simulation parameters in 4.2. We define the innovation efficiency of industry A_E=0.5. The knowledge input K_E=3. The output elasticity of knowledge input α_E=1. The additional cost C_E=2. The innovation efficiency of university A_U=0.5. The knowledge input K_U=2 .The output elasticity of knowledge input α_U=1. The additional cost C_U=2. The degree of complementarity of knowledge $\rho=1$. Since we already have the Figure when $\beta=0.5$ in 4.2, the both game sides will choose open innovation strategy to form the collaborative innovation alliance. Now we adjust the knowledge spillover coefficient from $\beta=0.5$ to $\beta=0.7$ then to $\beta=1$. We get the Figure 5 and Figure 6 to observe the evolutionary path of player one industry and player two university.



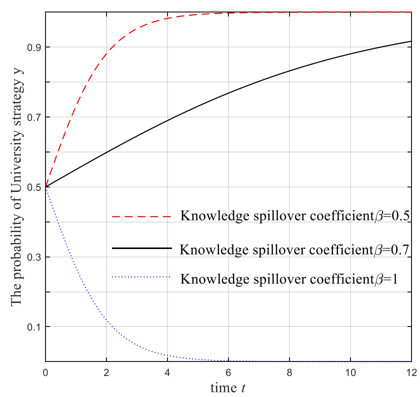


Figure 5 Knowledge spillover on industry's evolutionary path

Figure 6 Knowledge spillover on university's evolutionary path

As shown in Figure 5, the red dotted evolution curve is the evolution path of the industry when the knowledge spillover coefficient $\beta = 0.5$. The black solid evolution curve is the evolution path of the industry when the knowledge spillover coefficient $\beta = 0.7$. The blue dotted evolution curve is the evolution path of the industry when the knowledge spillover coefficient $\beta = 1$. All the three revolution curves start from point where the probability of open innovation $x(t) = 0.5$. As for industry group, because the knowledge spillover coefficient $\beta = 0.5$ is a lower value, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards the choice of open innovation strategy. When the knowledge spillover coefficient is improved to $\beta = 0.7$ and $\beta = 1$,because the knowledge spillover coefficient is a higher value, regardless of the probability of initial choice of open innovation strategy in the industry group, the final industry group is evolving towards the choice of closed innovation strategy. Through the comparison, we can conclude that higher level of knowledge spillovers can lead to free-rider problems from both sides of the game. Therefore, the game strategy of the industry will evolve to closed innovation strategy.

As shown in Figure 6, the red dotted evolution curve is the evolution path of the university when the knowledge spillover coefficient $\beta = 0.5$. The black solid evolution curve is the evolution path of the university when the knowledge spillover coefficient $\beta = 0.7$. The blue dotted evolution curve is the evolution path of the university when the knowledge spillover coefficient $\beta = 1$. All the three revolution curves start from point where the probability of open innovation $y(t) = 0.5$. As for the university group, because the knowledge spillover coefficient $\beta = 0.5$ is a lower value, regardless of the probability of initial choice of open innovation strategy in the university group, the final the university group is evolving towards the choice of open innovation strategy. When the knowledge spillover coefficient is improved to $\beta = 0.7$ and $\beta = 1$, because the knowledge spillover coefficient is a higher value, regardless of the probability of initial choice of open innovation strategy in the university group, the final university group is evolving towards the choice of closed innovation strategy. Through the comparison, we can conclude that higher level of knowledge spillovers can lead to free-rider problems from both sides of the game. Therefore, the game strategy of the university will evolve to closed innovation strategy.

5. Conclusions and recommendation

Collaborative innovation is the innovation behaviors of multiple subjects. The inherent mechanism is to discuss the possibility of collaborative innovation under uncertain conditions and to achieve the stability of collaboration and institutionalization. Based on evolutionary game theory, this paper analyzes the repeated game mechanism of industry, university from the perspective of bounded rationality. We find a few major points based on our model construction and simulation.

First of all, In the long-term collaborative innovation, if the innovation efficiency is high enough, industries, universities and research institute will eventually collaborate to achieve the "evolution stabilization strategy" of collaborative innovation.

Secondly, if we lower the degree of complementarity of knowledge, both industry and university will choose open innovation and form a collaborative innovation alliance. Meanwhile, the player who has higher knowledge input is more willing to choose open innovation strategy. Compare to innovation efficiency, knowledge complementarity is more effective for collaborative innovation alliance.

Last but not least, the most effective way to solve a free ride in a collaborative innovation alliance is to lower the possibility of knowledge spillover. When the level of knowledge spillover is too high, the game players as "economic man" will choose closed innovation strategy rather than open innovation strategy in order to improve the innovation output.

Based on above mentioned conclusions, the practical significance is that industries can increase collaboration with university to improve their own innovation capacity in developed industry areas. University should work on the topics which are relevant to regional development in order to improve research efficiency. The government should make use of policy guidance, developing intermediary organizations, system construction to increase the trust between industry and university. This will contribute to the efficiency of collaborative innovation. One of the limitation in our paper is that we only considered the effect of knowledge input on innovation return, which constrained our theoretical analysis. Given that there are more factors such as innovation cost, default penalties, the game model should be further developed in the next step.

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