Evolutionary game analysis of enterprises' technological innovation strategies

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Abstract

Different from general studies on competition and/or cooperation relationship of enterprises, the paper classified enterprises' technological innovation strategies into cooperation, neutrality and competition, and analysed the evolution of enterprises' relationship and strategy selection in technological innovation using the evolutionary game method and the MATLAB simulation technique. The paper drew the following conclusions: (1) the increase in technological content may cause two uncertain cases of enterprises' strategy, namely both parties chose the cooperation strategy, or one party chose the cooperation strategy while the other party chose the noncooperation strategy; (2) the increase in innovation revenue (coefficient) prompted enterprises to eventually tend towards the cooperative innovation strategy, no matter what the initial relationship between enterprises was; (3) the increase in the number of enterprises with the neutrality attitude promoted enterprise groups to tend towards cooperative innovation.

Keywords: technological innovation, evolutionary game, cooperation, neutrality, competition

1 Introduction

As a key for global competitiveness and business success, innovation is a critical element for boosting economies and societal development. Only those firms that foster innovation and handle innovation processes properly can survive eventually in the global market [1, 2]. Many scholars and managers have studied the technological innovation from various perspectives. Yuyin Yi et al. studied the opportunistic behaviors affecting the smooth development of cooperative R&D of enterprises by building an evolutionary game model, and proposed to solve such behaviours by means of supervision [3]. PRASHANT et al. believed that the higher the degree of openness between both parties in cooperation was, the more knowledge both parties acquired from the alliance; meanwhile, as the openness increased, it was more possible for cooperative partner to adopt opportunistic behaviours and cause more harms [4]. In order to find the operational mechanism of inter-enterprise cooperation, Zhaode Liu and Weiguo Zhang explored how enterprises chose the cooperative enterprise and cooperative innovation way by analysing the innovative behaviours of new high-tech enterprises [5]. Cristina and Carlos identified alternative strategic behaviours from the combination of competitive and cooperative attitudes and analysed the effect of co-opetitive strategy on technological innovation [6]. Liang Xu et al. believed that the competition & cooperation strategy of enterprises could promote technological innovation performance significantly and the cooperation strategy could promote technological innovation of enterprises greatly [7].

Unfortunately, as we shall highlight, many previous empirical studies exploring the technology innovation based on coopetition and/or cooperation relationship do not consider another relationship that is neither coopetition nor cooperation, namely neutrality. The paper introduces the view into the analysis on the evolutionary process of technological innovation, and believes that inter-enterprise relationship in technological innovation process includes the cooperation and the noncooperation, and the noncooperation includes the competition and the neutrality. In addition, the innovation is a process of technological complementation and benefit redistribution, so choosing which strategy depends on how the enterprise weighs the revenue from technological innovation, the risk loss caused by the potential opportunistic behaviour of cooperative partner, and the cost of technological innovation. Therefore, the paper chooses technological content, technological innovation revenue coefficient and ratio of neutrality as the impact factors in the analysis, and establishes a model of enterprises' technological innovation using the evolutionary game theory to make an in-depth analysis on the important factors affecting inter-enterprise relationship and various valuable cases of game evolution.

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2 Evolutionary model of technological innovation

The evolutionary game theory is based on biological evolutionism's basic principle - the survival of the fittest, and combines the game theory analysis with the dynamic evolution process analysis to reflect the process of dynamic strategy adjustment and equilibrium selection of participants [8]. Because there are information incompleteness and asymmetry in the technological innovation process, when deciding which strategy to adopt, the enterprise may use other enterprise groups' strategies for reference and adjust its strategy by copying other enterprises and using the trail-and-error method, and eventually tends to be stable. Therefore, the evolutionary game method is applicable to the study on the characteristics of inter-enterprise technological innovation strategy selection and corresponding evolutionary development.

2.1 HYPOTHESES OF MODEL

Hypothesis 1: Abstract some enterprises producing homogeneous products into two enterprise groups: A and B. As mentioned above, in the technological innovation, the two enterprise groups have two strategic choices: cooperation and noncooperation. Assume A has a probability of x to adopt noncooperation, and then it has a probability of $1-x$ to adopt cooperation; similarly, B has a probability of y to adopt noncooperation, and then it has a probability of $1-y$ to adopt cooperation.

Hypothesis 2: In the case that both groups adopt noncooperation, enterprises have different motives. That is, some enterprises may adopt noncooperation in the sense of competition due to an opportunistic motive or the overprotection to technologies; while, other enterprises may hold neutrality because of their large technological distance with other enterprises or for the purpose of high risk aversion. Assume the rates of neutrality in A and B are both expressed as z, and the rates of competition are both expressed as $1-z$.

Hypothesis 3: Table 1 shows the assumptions of the expression, meaning and value range of some coefficients necessary for model analysis.

TABLE 1 Relative Symbols and Their Meanings and Value Ranges

Symbol	Meaning	Value Range
q_1	Success rate of independent innovation	$0 \le q_1 \le 1$
q_2	Success rate of innovation with opportunistic behaviour	$0 \le q_2 \le 1$
q_3	Success rate of cooperative innovation	$0 \le q_3 \le 1$
α	Coefficient of technological innovation revenue	$\alpha > 1$
W	Technological content (difficulty) of technological innovation project	$W \ge 0$
λ_1	Cost coefficient of competition	$\lambda_1 \ge 1$
λ_2	Cost coefficient of opportunism	$\lambda_2 \ge 1$
λ_3	Cost coefficient of cooperative innovation	$\lambda_3 \ge 1$
λ_4	Cost coefficient of neutral innovation	$\lambda_4 \ge 1$
k	Competition index	$k > 1$

Hypothesis 4: For simplicity, assume enterprise revenue has a linear relation of $q_i \alpha W$ ($i = 1,2,3$) with the successful rate of technological innovation and technological content. Then, under the condition of technological content W, if both parties adopt noncooperation, they get the revenue of $q_1 \alpha W$; if one party adopts neutrality while the other party adopts cooperation, two parties still accomplish their innovations independently because they fail to achieve cooperative innovation eventually, and exactly for this reason, they still both get the revenue of $q_1 \alpha W$; if one party seems to cooperate but actually adopts competition while the other party adopts cooperation, there will be an opportunistic phenomenon - the party of competition may act as a free rider. In this case, both parties may get the revenue of $q_2 \alpha W$ from this form of cooperation; when both parties adopt cooperative innovation, their revenues are both assumed as $q_3 \alpha W$.

Hypothesis 5: Assume the total cost of technological innovation changes as the enterprise's innovation strategy changes.

(1) When both parties adopt competition, or one party keeps neutrality while the other party adopts competition, with the certain technological content W, the competition enterprise's initial cost input is basically in direct proportion to its technological content (approaching a linear function). As the technological innovation goes deeper, the enterprise gives more positive comments on the technology's importance and future prospect, thus increasing cost input. When the conditions are fitted, we find the relations of elements more approach an exponential function. Therefore, assume the cost as $c_1 = \lambda_1 W^k$.

(2) When one party adopts cooperative innovation while the other party adopts competition, the party of competition shows an opportunistic behaviour, trying to learn knowledge from the other party and terminating the cooperation after acquiring the technology. So under the condition of certain technological content W, the enterprise's initial cost input is basically in direct proportion to its technological content (approaching a linear relation). However, as the technological innovation goes deeper, cost input doesn't change as technological content changes, and is about to reach a stable value. Therefore, assume the cost as $c_2 = \lambda_2 \ln W$.

(3) When both parties adopt the cooperative innovation, the cost input is in direct proportion to technological content, namely $c_3 = \lambda_3 W$.

(4) When both parties or one party adopts neutrality, the innovation cost of neutral enterprise is $c_4 = \lambda_4 W$.

2.2 EVOLUTIONARY GAME MODEL

According to the hypotheses above, Table 2 shows the payoff matrix (including 9 cases) of the technological innovation mode selections of A and B.

TABLE 2 Pay-off matrixes of Evolutionary Game of A and B (include 9 cases)

Enterprise Group A \ Enterprise Group B		Noncooperation with a Probability of y: Neutrality with a Probability of z	Noncooperation with a Probability of y: Competition with a Probability of $1-z$	Cooperative Innovation with a Probability of $1-y$
Noncooperation with a Probability of x	Neutrality with a Probability of z	$(q_1\alpha W-\lambda_4 W,$ $q_1\alpha W-\lambda_4 W)$	$(q_1\alpha W-\lambda_4 W,$ $q_1\alpha W-\lambda_1 W^k)$	$(q_1\alpha W-\lambda_4 W,$ $q_1\alpha W-\lambda_3 W)$
	Competition with a Probability of $1-z$	$(q_1\alpha W-\lambda_1 W^k,$ $q_1\alpha W-\lambda_4 W)$	$(q_1\alpha W-\lambda_1 W^k,$ $q_1\alpha W-\lambda_1 W^k)$	$(q_2\alpha W-\lambda_2\ln W,$ $q_2\alpha W-\lambda_3 W)$
Cooperative Innovation with a Probability of $1-x$		$(q_1\alpha W-\lambda_3 W,$ $q_1\alpha W-\lambda_4 W)$	$(q_1\alpha W-\lambda_3 W,$ $q_1\alpha W-\lambda_4 W)$	$(q_2\alpha W-\lambda_3 W,$ $q_2\alpha W-\lambda_2\ln W)$

Table 2 can be simplified and sorted into Table 3 in which the payoff matrix includes 4 cases. Table 3 shows that when both parties adopt noncooperation, each of them get the revenue of D; when one party adopts cooperative innovation while the other party adopts noncooperation, the party of noncooperation gets the revenue of E, and the party of cooperative innovation gets the revenue of F; when both parties adopt cooperative innovation, they both get the revenue of G.

TABLE 3 Payoff Matrix of Evolutionary Game of A and B (include 4 cases)

Enterprise Group A \ Enterprise Group B	Noncooperation with a Probability of y	Cooperative Innovation with a Probability of $1-y$
Noncooperation with a Probability of x	(D,D)	(E,F)
Cooperative Innovation with a Probability of $1-x$	(F,E)	(G,G)

Apparently, the expressions of D, E, F and G in Table 3 can be obtained by substituting corresponding contents in Table 2. The expressions are as follows:

$$D=q_1\alpha W-(1-z)\lambda_1 W^k-z\lambda_4 W, \tag{1}$$

$$E=z(q_1\alpha W-\lambda_4 W)+(1-z)(q_2\alpha W-\lambda_2\ln W), \tag{2}$$

$$F=\alpha Wz(q_1-q_2)+q_2\alpha W-\lambda_3 W, \tag{3}$$

$$G=q_3\alpha W-\lambda_3 W. \tag{4}$$

According to Table 3, U_{11}, U_{12} and $\overline{U_1}$, which are the fitness functions and the average fitness function when A adopts noncooperation and cooperation, can be expressed as:

$$U_{11}=Dx+E(1-x), \tag{5}$$

$$U_{12}=Fx+G(1-x), \tag{6}$$

$$\overline{U_1}=xU_{11}+(1-x)U_{12}. \tag{7}$$

Similarly, when B adopts noncooperation and cooperation, the fitness functions and the average fitness functions U_{21}, U_{22}, $\overline{U_2}$ are respectively:

$$U_{21}=Dx+E(1-x), \tag{8}$$

$$U_{22}=Fx+G(1-x), \tag{9}$$

$$\overline{U_2}=yU_{21}+(1-y)U_{22}. \tag{10}$$

According to the duplicator dynamic equation, the following two-dimensional differentiable dynamic system can be obtained:

$$\begin{cases}\frac{dx}{dt}=x(U_{11}-\overline{U_1})=x(1-x)[(D-E-F+G)y+E-G]\\ \frac{dy}{dt}=y(U_{21}-\overline{U_2})=y(1-y)[(D-E-F+G)x+E-G]\end{cases}. \tag{11}$$

Then, let $\frac{dx}{dt}=\frac{dy}{dt}=0$, and get the following five equilibrium points of equation set: $(0,0)$, $(0,1)$, $(1,0)$, $(1,1)$, (x_0,y_0), among which $x_0=y_0=\frac{G-E}{D-E-F+G}$ ($x_0,y_0\in[0,1]$).

After calculation, the Jacobian matrix J is:

$$J=\begin{bmatrix}(1-2x)[(D-E-F+G)y+E-G] & x(1-x)(D-E-F+G)\\ y(1-y)(D-E-F+G) & (1-2y)[(D-E-F+G)x+E-G]\end{bmatrix}. \quad (12)$$

According to the stability theory of nonlinear differential equation, the stability of balance points can be determined by the sign of the Jacobian matrix's characteristic root [9]. Table 4 shows the values of matrix J 's determinant $DetJ$ and trace trJ in equilibrium points and other related information.

TABLE 4 Evolution Path of enterprise's technological innovation strategy selection

Condition	Balance Point	Sign of $DetJ$	Sign of trJ	Local Stability
case1: $D-F>0$, $G-E>0$ Note: there are five balance points	(0,0)	+	−	ESS
	(0,1)	+	+	Unstable point
	(1,0)	+	+	Unstable point
	(1,1)	+	−	ESS
	(x_0, y_0)	−	0	saddle point
Case 2: $D-F<0$, $G-E>0$ Note: there are four balance points, and $(x_0, y_0)\notin[0,1]$	(0,0)	+	−	ESS
	(0,1)	−	±	saddle point
	(1,0)	−	±	saddle point
	(1,1)	+	+	Unstable point
Case 3: $D-F>0$, $G-E<0$ Note: there are four balance points, and $(x_0, y_0)\notin[0,1]$	(0,0)	+	+	Unstable point
	(0,1)	−	±	saddle point
	(1,0)	−	±	saddle point
	(1,1)	+	−	ESS
Case 4: $D-F<0$, $G-E<0$ Note: there are five balance points	(0,0)	+	+	Unstable point
	(0,1)	+	−	ESS
	(1,0)	+	−	ESS
	(1,1)	+	+	Unstable point
	(x_0, y_0)	−	0	saddle point

According to the formulations (1) to (4), the following formulations can be obtained:

$$D-F=\alpha W(q_1-q_2)(1-z)-(1-z)\lambda_1 W^k - z\lambda_4 W+\lambda_3 W\ , \quad (13)$$

$$G-E=q_3\alpha W-\lambda_3 W - z(q_1\alpha W-\lambda_4 W)-(1-z)(q_2\alpha W-\lambda_2 \ln W)\ . \quad (14)$$

3 Numerical simulation of evolutionary game model

3.1 ANALYSIS ON SYSTEM'S ASYMPTOTIC STABILITY AND PARAMETER SENSITIVITY

To make the simulation analysis, we need to assign values to related parameters. Assume A's probability to adopt noncooperation $x=0.3$, B's probability to adopt noncooperation $y=0.7$, the success rate of technological innovation in the case of noncooperation $q_1=0.4$, the success rate of technological innovation in the case of opportunistic behaviour $q_2=0.5$, the success rate of technological innovation in the case of cooperative innovation $q_3=0.8$, the competition index of in the case of competition strategy $k=1.5$, the cost coefficient of technological innovation in the case of competition $\lambda_1=6$, the cost coefficient of technological innovation in the case of opportunistic behaviour $\lambda_2=4$, the cost coefficient of technological innovation in the case of cooperation $\lambda_3=5$, the cost coefficient of technological innovation in the case of neutrality $\lambda_4=4$, and the probability of neutrality in the case of noncooperation $z=0.4$.

According to the discussion above and values assignment to parameters, the next section further analyzes each case.

Case 1: To meet conditions of $D-F>0$ and $G-E>0$, assume the coefficient of technological innovation revenue $\alpha=8$ and the technological content of technological innovation $W=4$. In this case, the system's evolutionary phase diagram and evolution path are shown in fig.1a and fig.1b. In the figures, A and B finally become stable in points (0,0) and (1,1) after a period of game. The system has two stable points, so which one is the final stable point depends on the initial values of x and y. That is, in the context that most enterprises in the market tend to adopt cooperative innovation, people are guided to adopt cooperative innovation eventually. However, when most enterprises in the market adopt noncooperation, both A and B eventually adopt noncooperation after a period of game, just as shown in fig.1b.

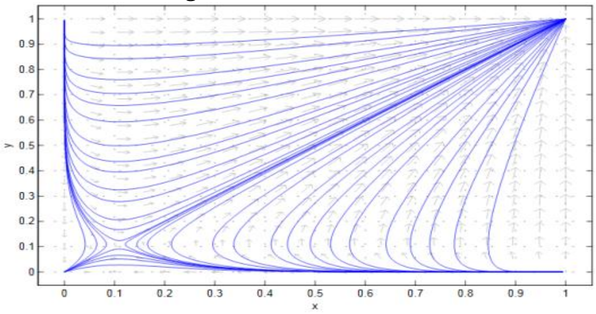

FIGURE 1a Phase Diagram in case 1

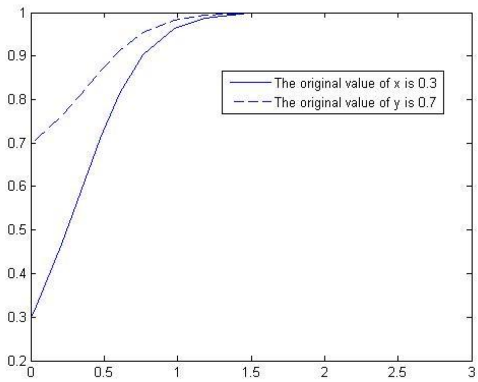

FIGURE 1b Evolutionary Path with stable point (1,1)

Adjust the value of W, α and z respectively, the game strategies of A and B may evolve correspondingly.

(1) Adjust the initial value of technological content W. Make $W = 4, 6, 10, 14, 16$ in turn. Fig.2a and fig.2b show that the stable point of the game between A and B changes from point $(1,1)$ to point $(0,0)$, and when the number of W's value exceeds 16, the overall case evolves into case 2 with only one stable point (0,0).

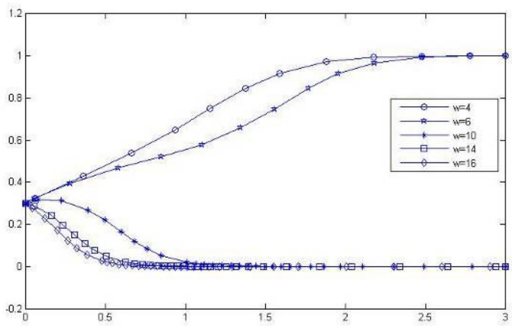

FIGURE 2a A's evolutionary Path figure as W increase

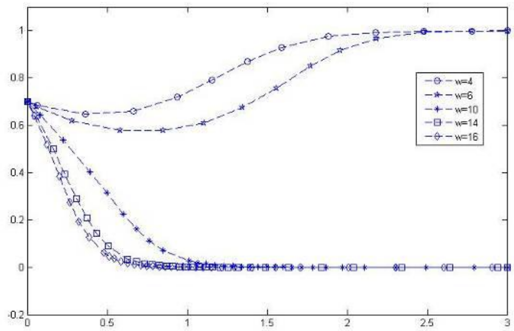

FIGURE 2b B's evolutionary Path figure as W increase

(2) Adjust the initial value of α. Make $\alpha = 8, 14, 20, 25, 28$ in turn. Fig.3a and fig.3b show that the stable strategy of A and B also changes from point $(1,1)$ to point $(0,0)$. It means that the enterprise is willing to turn from independent innovation to cooperation as technological innovation revenue increases.

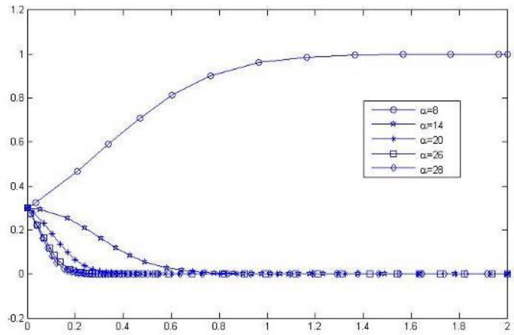

FIGURE 3a A's evolutionary Path figure as α increase

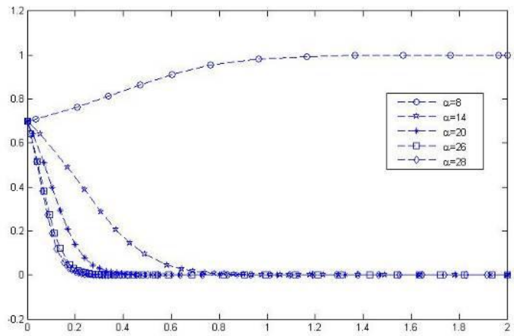

FIGURE 3b B's evolutionary Path figure as α increase

(3) Change the value of z. Make z =0.4, 0.5, 0.6, 0.7, 0.8 in turn. Fig.4a and fig.4b show that as the number of enterprises of neutrality increases, the stable strategy of A and B shifts from (1,1) to (0,0) gradually. The phenomenon has important significance. It indicates that the increase in the number of neutrality may help to form inter-enterprise cooperation under certain conditions.

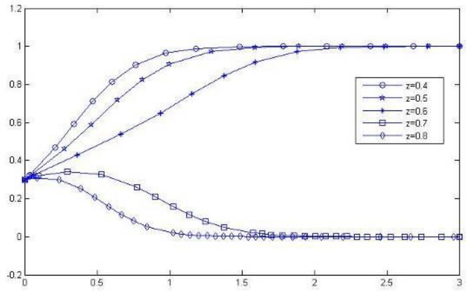

FIGURE 4a A's evolutionary Path figure as z increase

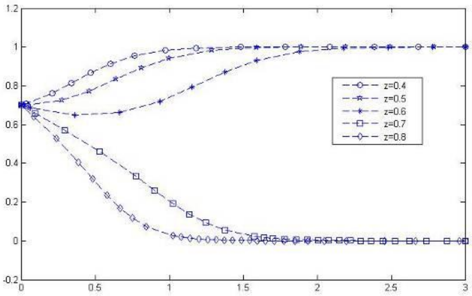

FIGURE 4b B's evolutionary Path figure as z increase

Case 2: To meet conditions of $D-F<0$ and $G-E>0$, assume the coefficient of technological innovation returns $\alpha=30$ and the technological content of technological innovation $W=18$. Fig.5a and fig.5b show the evolutionary path of the relationship between A and B under the conditions. In this case, the system has only one stable point (0,0), which means after a period of evolution, A and B can only adopt cooperation eventually to achieve bigger development, no matter what the initial ratios of cooperative innovation in A and B are.

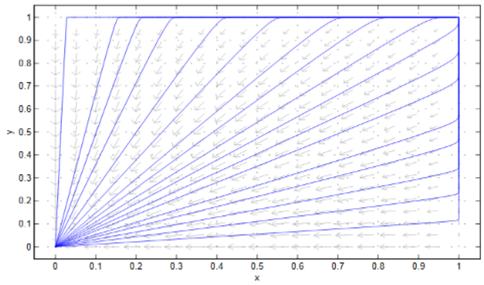

FIGURE 5a Phase Diagram in case 2

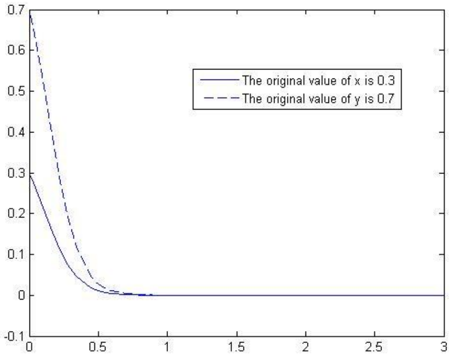

FIGURE 5b Evolutionary Path with stable point (0,0)

Values of parameters W, α and z can be adjusted respectively to analyse their effects on the game strategies of A and B.

(1) Change the value of W. Make W =18, 22, 26, 30, 35 in turn. Fig.6a and fig.6b show that enterprise groups A and B fast approaches stable point $(0,0)$, which represents cooperation as technological content increases.

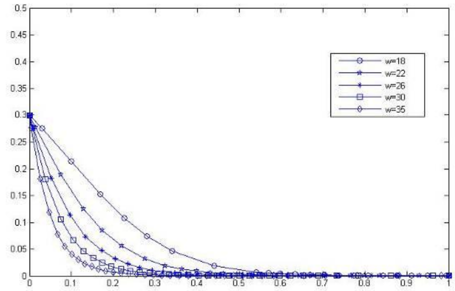

FIGURE 6a A's evolutionary Path figure as W increase

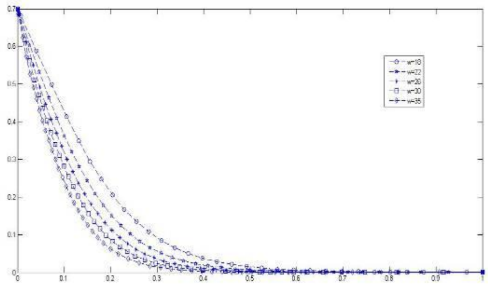

FIGURE 6b B's evolutionary Path figure as W increase

(2) Change the value of α. Make α =30, 35, 40, 45, 50 in turn. Fig.7a and fig.7b show the technological innovation revenues of A and B increase as the value of innovation coefficient α increases. This result promotes enterprises to adopt cooperative innovation.

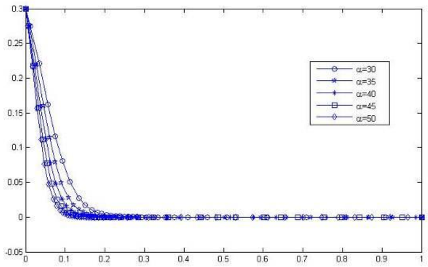

FIGURE 7a A's evolutionary Path figure as α increase

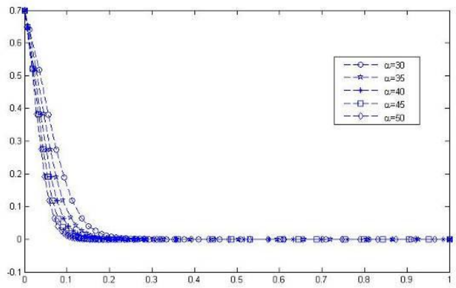

FIGURE 7b B's evolutionary Path figure as α increase

(3) Change the value of z. Make z =0.4, 0.5, 0.6, 0.7, 0.8 in turn. Fig. 8a and fig. 8b show that as z increases A and B both fast tend towards stable point $(0,0)$, which represents cooperation.

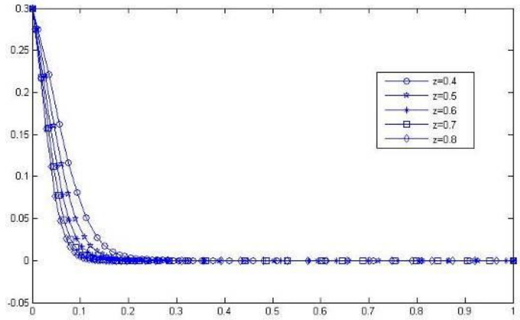

FIGURE 8a A's evolutionary Path figure as z increase

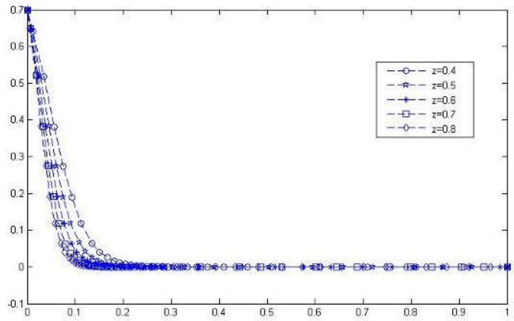

FIGURE 8b B's evolutionary Path figure as z increase

Case 3: To meet conditions of $D-F>0$ and $G-E<0$, assume the coefficient of technological innovation revenue $\alpha=4$ and the technological content of technological innovation $W=6$. Fig.9a and fig.9b show the evolutionary diagram and path in this condition. It can be seen the system has one stable point (1,1), which means after a period of evolution, A and B eventually adopt noncooperation, no matter what the initial ratios of noncooperation in A and B are.

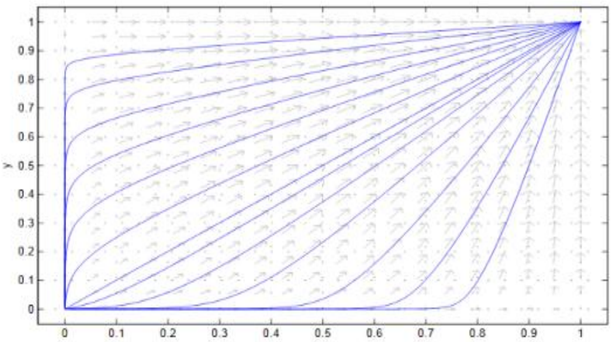

FIGURE 9a Phase Diagram in case 3

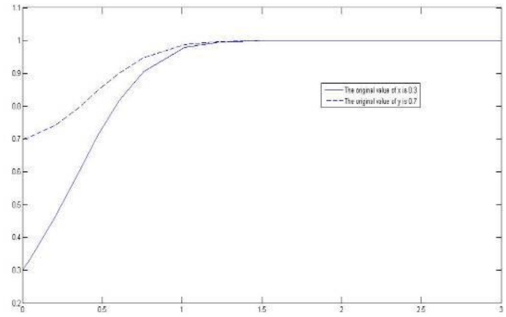

FIGURE 9b Evolutionary Path with stable point (1,1)

Values of parameters W, α and z can be adjusted respectively to analyse their effects on the game strategies of A and B.

(1) Change the value of the parameter of technological content W. Make W =6, 12, 15, 18, 21 in turn. Fig.10a and fig.10b show the evolutionary path of the relationship between A and B. Comparing fig.10a with fig.10b, we can see A slows down when approaching "1", while B is not sensitive to the increase of W. Therefore, as technological content increase, the evolution approaches point (0,1) which means one party cooperates while the other party doesn't. It indicates the game result may have a qualitative change over time

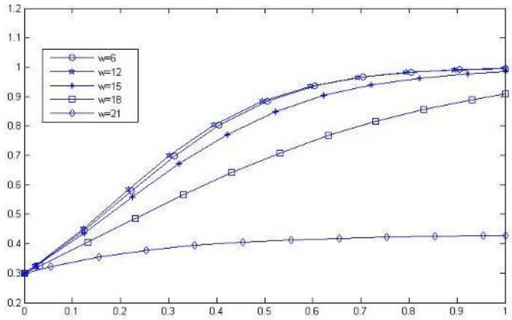

FIGURE 10a A's evolutionary Path figure as W increase

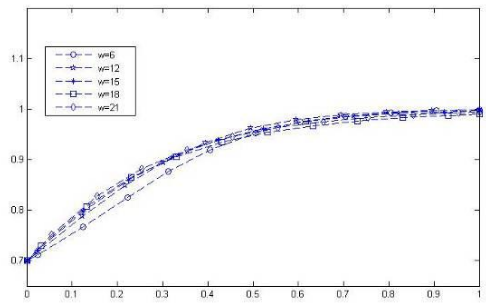

FIGURE 10b B's evolutionary Path figure as W increase

(2) Change the value of α. Make α =4, 5, 6, 8, 10 in turn. Fig.11a and fig.11b show that as technological innovation revenue (coefficient) increase, the system slows down when approaching stable point $(1,1)$.

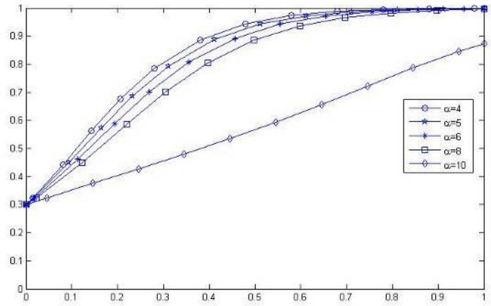

FIGURE 11a A's evolutionary Path figure as α increase

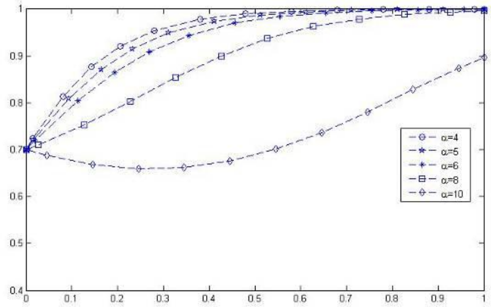

FIGURE 11b B's evolutionary Path figure as α increase

(3) Change the value of z . Make z =0.4, 0.5, 0.6, 0.7, 0.8 in turn. Fig.12a and fig.12b show that as the number of neutral enterprise increases, the system slows down when approaching stable point (1, 1).

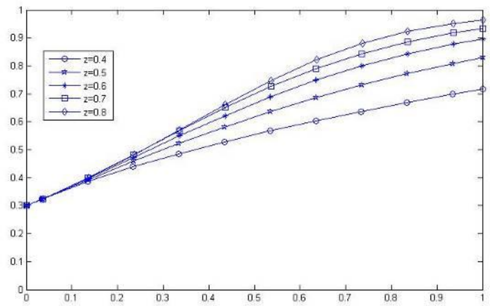

FIGURE 12a A's evolutionary Path figure as z increase

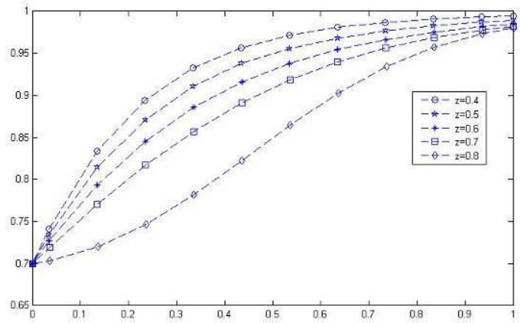

FIGURE 12b B's evolutionary Path figure as z increase

Case 4: To meet conditions of $D-F<0$ and $G-E<0$, assume the coefficient of technological innovation revenue $\alpha=8$ and the technological content of technological innovation $W=25$. Fig.13a and fig.13b show the evolutionary diagram and path under this condition. According to these figures, A and B become stable at points $(0,1)$ and $(1,0)$. It means one party adopts cooperation while the other party adopts noncooperation. The final stable point is affected by the initial numbers of enterprise A and B adopting cooperation or noncooperation.

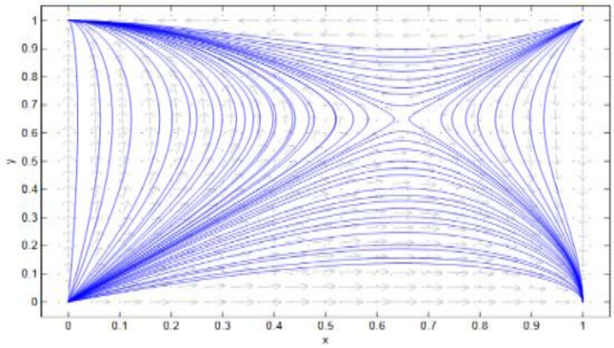

FIGURE 13a Phase Diagram in case 4

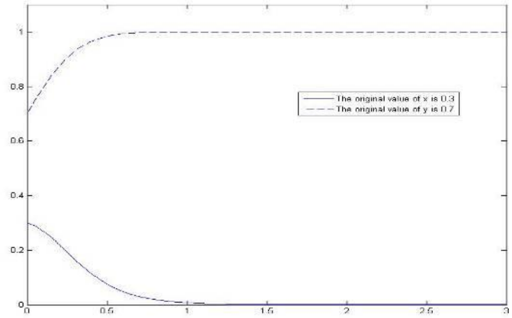

FIGURE 13b Evolutionary Path with stable point (0,1)

Values of parameters W , α and z can be adjusted respectively to analyze their effects on their game strategies of A and B.

(1) Change the value of W . Make W =25, 30, 35, 40, 45 in turn. Fig.14a and fig.14b show A and B approach stable point (0, 1) faster as the value of W increases.

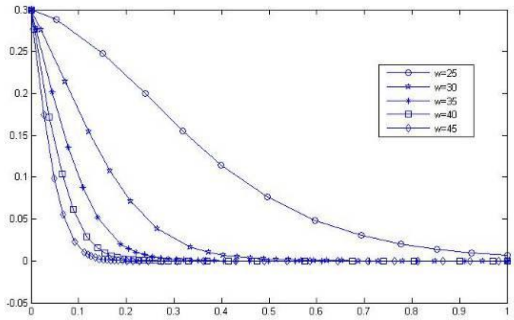

FIGURE 14a A's evolutionary Path figure as W increase

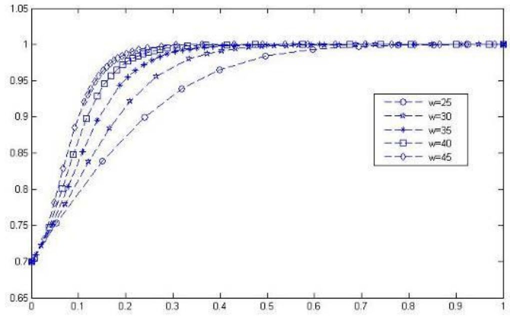

FIGURE 14b B's evolutionary Path figure as W increase

(2) Change the value of α. Make α =8, 9, 12, 16, 20 in turn. Fig.15a and fig.15b show that as the coefficient of technological innovation revenue increases, enterprise group A approaches the stable value "0" fast, while enterprise group B slows down when approaching the stable value point "1". It indicates as the technological innovation revenue (coefficient) increases, it's harder to approach the point (0,1), which means one party cooperates while the other party does not.

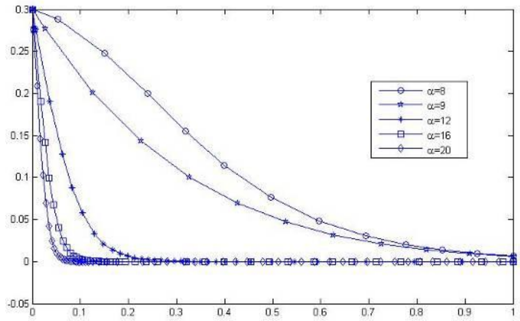

FIGURE 15a A's evolutionary Path figure as α increase

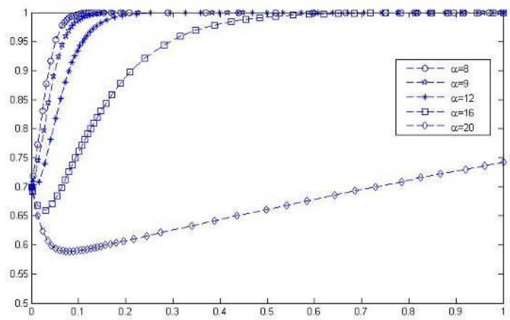

FIGURE 15b B's evolutionary Path figure as α increase

(3) Change the value of z. Make z =0.4, 0.5, 0.6, 0.7, 0.8 in turn. Fig.16a and fig.16b show that enterprise group A approaches value point "0" faster, while enterprise group B slows down when approaching stable value point "1". It indicates that as the ratio of neutral enterprise increases, it's harder for the result of evolutionary game to approach point (0,1).

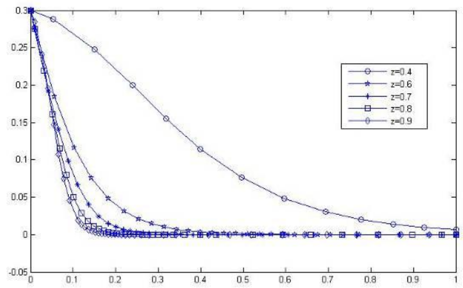

FIGURE 16a A's evolutionary Path figure as z increase

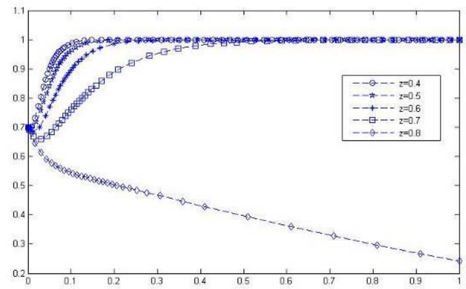

FIGURE 16b B's evolutionary Path figure as z increase

3.3 FURTHER DISCUSSION

According to the analysis on the four cases above, a further discussion is made in this section.

(1) The technological content of innovation object has great effects on inter-enterprise relationship. The discussion above shows that in case 1 and case 2, the increase in technological content makes the game result change into (cooperation, cooperation) eventually. The main reason for the result is, when carrying out an innovation activity with a high technological content, the enterprise tends to accomplish the innovation task with the help of other enterprises due to its limited innovation ability, and thus is willing to adopt cooperation. In case 3 and case 4, the increase in technological content makes two parties in the game fast approach a situation that one party cooperates while the other party doesn't. The reason is some enterprises begin to change innovation strategies facing the innovation risks brought by high technological content, and hope to accomplish the technological innovation task through the cooperation with others, as the technological content increases in case 3; in case 4, the enterprise of cooperation hopes to make cooperation more eagerly, while the enterprise of noncooperation is more reluctant to make cooperation, because of the increase in technological content. The noncooperation comes from two motives: first, facing the projects with high technological contents, some enterprise hope to steal the core technology from their partners through opportunistic behaviours; second, some enterprises doubt about the success rate of cooperative innovation, thus adopting neutrality (unwilling to cooperate) to avoid innovation risks. Over time, the results in case 3 and case 4 may both result in a situation that enterprises don't want to carry out innovation activities with high

technological contents any more, which is the last thing people want.

(2) Innovation revenue is the driving force for the establishment or maintenance of inter-enterprise relationship in technological innovations. As everyone knows, pursuing the maximization of benefit is the start point and one of end points of enterprise activities, so the analysis on technological innovation revenue has great effects on enterprises' innovation strategy selection. It can bring about a cooperation relationship, help to maintain cooperation, slow down the forming of noncooperation, and even bring about new cooperation relationships. It has been expressed clearly in the discussion above.

(3) Establishing and maintaining a certain amount of neutral relationships are very important for the cooperative innovation of enterprises. Different from general studies on competition and/or cooperation relationship, the paper subdivides the inter-enterprise technological innovation strategies into cooperation, neutrality and noncooperation. The study in the paper indicates the increase of the enterprises of neutrality eventually helps to form or approach a cooperation relationship of enterprises, no matter in which case. Therefore, identifying and maintaining neutral enterprises and keeping them from becoming competitors are very crucial in enterprise relationship management, which can lay a solid foundation for inter-enterprise cooperation in the future. Although the implementation of the strategy needs certain cost, the cost is nothing compared with the cost of changing a competitor into a partner.

4 Conclusions

The paper classifies enterprises' technological innovation strategies as cooperation, noncooperation and neutrality using the idea and method of system analysis, and analyses the evolution of inter-enterprise relationship and strategy selection in technological innovation using the evolutionary game method and MATLAB simulation technique, and finally draws some valuable conclusions. It should be noticed that the study in the paper is still limited. For instance, for simplicity, the paper expresses the revenues of two parties both as $q_2 \alpha W$ in the case that one party adopts competition while the other party adopts cooperation. In fact, the assumption may be different from the practical situation. Such problems should be solved in further and in-depth studies.

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