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Evolutionary Game Analysis of Competition and Cooperation of Green Technology Innovation among Enterprises under Government Incentive

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Abstract: *Based on the situation of green technology innovation and development of enterprises, this paper studies the evolution of the competitive and competitive game relationship of green technology innovation among enterprises with different government incentives by establishing an evolutionary game model. Matlab software is used to numerically calculate the evolutionary path of the game between government and enterprises and the position change of equilibrium point. The dynamic evolution of collaborative innovation behavior and interaction among enterprises is discussed. The results show that in the process of green technology innovation, enterprises will be more inclined to green technology innovation cooperation only when they are fully "motivated". In the process of innovation and development of green technology among government enterprises, it has a very important influence. Under the reasonable supervision of the enterprise government, it is easier to optimize the allocation of innovative resources, effectively reduce the situation that enterprises have no green technology innovation cooperation, realize better control of innovation costs, and then bring double benefits of economic and social benefits through the development of technological innovation.*

Keywords: *Government; Evolutionary game; Green technology; Competition and cooperation; Matlab*

1. Introduction

In recent years as the deepening of the understanding of environment protection and sustainable development, and double carbon strategy of gradual, people thirst for green economy development more and more intense, under the background of advocating green products international, the government encourages enterprises to vigorously to develop green technology, at the same time, with the development of green technologies, green products industry standards is also in constant increase.

Green technology is not only a favorable means for enterprises to compete, but also relates to the comprehensive competitive strength of a country or region. Under the background of more and more obvious trend of international economic integration, some countries have adopted a series of trade restriction measures in order to protect their own enterprises and markets, among which green trade barrier is one of the main trade barriers in the field of international trade [1]. In the process of green technology innovation and development, a single enterprise has limitations in terms of scale and technological breakthroughs, and it is difficult to maintain a stable advantage in technological innovation. The relationship between competition and cooperation among enterprises is also more complex and changeable, and a benign cooperation relationship between enterprises in green technology innovation can effectively improve the green technology level and comprehensive strength of domestic enterprises. Therefore, it is one of the key problems to be solved at this stage to explore the evolution of competition and cooperation relationship of green technology innovation and how to improve the cooperation ability of green technology innovation in the market.

2. Literature Review

At present, domestic and foreign scholars have abundant literature on the research background of green technology innovation in supply chain, and there are mainly two types of relevant literature: one is the research on green supply chain management decision; The other is the impact of government incentives on enterprise green technology innovation.

In the study of green supply chain management decision. Asghari Tooba et al. [2] used Stackelberg

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game model to study the three-level green supply chain composed of manufacturers, retailers and service providers, and analyzed their coordination strategies under different cooperation structures. Peng et al. [3] consideration the game behavior between the manufacturers and retailers, the four through the establishment of green supply chain game model, using the revenue-sharing contract coordination game behavior between manufacturers and retailers, from longitudinal aspects has carried on the detailed analysis of the supply chain, this also for the study of the analysis of the game relation between enterprises laid a solid foundation. In order to reflect the research on supply chain management in a more detailed way, different preferences of enterprises for environmentally friendly goals should be taken into account. Li et al. [4] took the green transformation of enterprises as the starting point and combined with the comparison of three green supply chain models to build a green supply chain model for manufacturers and retailers considering different goals. The influence of environmental preferences of manufacturers and retailers on supply chain system is analyzed.

Research on the influence of government incentive on enterprise green technology innovation. Using PIM, DEA and mediating effect test, Zhao et al. [5] empirically tested the green development of environment at the provincial level in China from 2004 to 2019. They believed that it was necessary to increase R&D investment and guide green innovation for pollution control, and government subsidies had a positive impact on enterprises' green technology innovation. [6] It can solve the capital problems that enterprises may encounter in the process of green technology innovation, and effectively reduce the cost and risk of their research and development. In the research on the development of green technology, it is found that the development of green technology can not only solve environmental problems, but also promote economic growth. [7] Gu et al. [8] believe that enterprise green technology is an important factor for the success of green transformation. The research also explains why China strongly encourages enterprises to actively undertake green technology innovation. In the process of green technology development, enterprises will try to acquire and adopt innovative technologies only when they are convinced that the adoption of new technologies can increase their profits. [9] Sharing green technologies or R&D costs will also bring market opportunities to enterprises, which can reduce the fierce market competition to a certain extent.

Through literature review, it is found that scholars mainly use the traditional game in their research. Starting from different simulation models and the impact of policy intensity, scholars mainly study the impact of environmental regulation on green technology innovation, and focus on the collaborative relationship between the upstream and downstream of the supply chain in green technology innovation. The competition and cooperation relationship between enterprises in different supply chains is less studied, which has an important impact on the development and innovation of green technology. In the process of green technology development of enterprises, we also believe that technological innovation cooperation between enterprises can strengthen the technological innovation ability of enterprises, [10] and then bring more technological innovation output and economic benefits.[11] This paper uses the evolutionary game method to build a game model of the competition and cooperation relationship between green technology innovation among enterprises, analyzes the evolution of the competition and cooperation relationship, and seeks how to achieve a benign competition and cooperation relationship between green technology innovation among enterprises, in order to provide certain reference value for national policies and enterprise development.

3. Game model of competition and cooperation of green technology innovation in enterprises

3.1. Basic Assumptions

In the early stage of the game, it is assumed that the degree to which the government stakeholders choose the "incentive" strategy is Z; The probability that enterprise interest subject A chooses "innovation cooperation" strategy is X; The probability that enterprise interest subject B chooses the strategy of "innovation cooperation" is y, and x, y, z∈ [0,1], which are all functions of time t. It is assumed that enterprise A and Enterprise B have their own strengths. Enterprise A has A better management system and excellent talent reserve, while enterprise B has more market information and product operation mode. Due to the uncertainty of collaborative innovation, the risk preferences of game participants are also uncertain, so it is difficult for enterprises to achieve complete information conditions and cannot be estimated according to expected utility theory. Their strategic choice is their own subjective feelings to make decisions on strategic value.

Assume that when two firms "do not cooperate in innovation", the normal income obtained by firms A and B is "e1, e2". The total revenue (actual revenue and potential revenue) obtained by enterprises

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from technical cooperation with each other is "R1, R2". If one party chooses "innovation cooperation" and the other party chooses "non-innovation cooperation", the income obtained is "R'1, R'2". The revenue of green technology innovation cooperation obtained by government financial support is "r1, r2"; Innovation cooperation cost is "c1, c2"; The total effort (the sum of cost and risk) of enterprises in the process of green technology innovation cooperation is "C1, C2". Under the condition of government incentive, when enterprises choose "no innovation cooperation", the loss obtained is "s1, s2"; In the case of green technology innovation cooperation between enterprises, the social green level is improved, and the government will get "f1". If one party in the enterprise has innovative cooperation and the level of social green technology is improved, the government will gain "f2"; The cost paid by the government to choose the incentive strategy is "c0"; In the case of green technology innovation cooperation between enterprises under the government incentive strategy, the revenue that technology growth can bring to the government is "u1"; Under the government incentive strategy, when the enterprise innovates, the technological growth makes the government gain "u2".

3.2. Return matrix

In the construction of the multi-party evolutionary game model, the returns of the government, enterprise A and enterprise B are shown in Table 1.

Table 1: Income Matrix of Enterprise A, Enterprise B and Government

Game participants		government incentive (z)	Government not incentive (1-Z)
Enterprise A Innovation Cooperation (X)	Enterprise B Innovation Cooperation (Y)	$(e_1+R_1+r_1-C_1, e_2+R_2+r_2-C_2, f_1+u_1-c_0)$	$(e_1+R_1-C_1, e_2+R_2-C_2, f_1)$
	Enterprise B does not cooperate in innovation (1-y)	$(e_1-s_1, e_2+R'_2+r_2-C_2, f_2+u_2-c_0)$	$(e_1, e_2+R'_2-C_2, f_2)$
Enterprise A does not cooperate in innovation (1-X)	Enterprise B Innovation Cooperation (Y)	$(e_1+R'_1+r_1-C_1, e_2-s_2, f_2+u_2-c_0)$	$(e_1+R'_2-C_1, e_2, f_2)$
	Enterprise B does not cooperate in innovation (1-y)	$(e_1-s_1, e_2-s_2, -c_0)$	$(e_1, e_2, 0)$

3.3. Multi-evolutionary game strategy solution

The revenue expectation of enterprise A is a_{11} and a_{12}, and its average revenue expectation is $\overline{a}_1$. According to the revenue matrix of multi-party game, its calculation expression can be shown in Equations (1) to (3):

$$a_{11} = x[z(e_1+R_1+r_1-C_1)+(1-z)(e_1+R_1-C_1)]+(1-x)[z(e_1+R'_1+r_1-C_1)+(1-z)(e_1+R'_2-C_1)] \tag{1}$$

$$a_{12} = x[z(e_1-s_1)+(1-z)e_1]+(1-x)[z(e_1-s_1)+(1-z)e_1] \tag{2}$$

$$\overline{a}_1 = ya_{11}+(1-y)a_{12} \tag{3}$$

The revenue expectation of enterprise B is a_{21} and a_{22}, and its average income expectation is $\overline{a}_2$. According to the multi-party game income matrix, its calculation expression can be shown in Equations (4) to (6):

$$a_{21} = y[z(e_2+R_2+r_2-C_2)+(1-z)(e_2+R_2-C_2)]+(1-y)[z(e_2+R'_2+r_2-C_2)+(1-z)(e_2+R'_2-C_2)] \tag{4}$$

$$a_{22} = y[z(e_2-s_2)+(1-z)e_2]+(1-y)[z(e_2-s_2)+(1-z)e_2] \tag{5}$$

$$\overline{a}_2 = xa_{21}+(1-x)a_{22} \tag{6}$$

According to the above calculation results of the three parties' income and the basic principle of the replication dynamic equation of evolutionary game, the replication dynamic equation of the interest body of enterprise A and enterprise B can be obtained as follows:

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$$F(y)=\frac{dy}{dt}=y(a_{11}-\overline{a}_1)=y(1-y)(a_{11}-a_{12})=y(1-y)\{z[s_1+r_1+(1-x)(R'_1-R'_2)]+R'_2-C_1+x(R_1-R'_2)\} \tag{7}$$

$$F(x)=\frac{dx}{dt}=x(a_{21}-\overline{a}_2)=x(1-x)(a_{21}-a_{22})=x(1-x)[z(s_2+r_2)+yR_2+(1-y)R'_2-C_2] \tag{8}$$

Five local equilibrium points of game matrix can be obtained by calculation. Where (0,0), (0,1), (1,0) and (1,1) are four pure strategy equilibrium points. The coordinates of the point P* are shown below:

$$\left(\frac{C_1-z(s_1+r_1+R'_1)-(1-z)R'_2}{R_1-(1-x)R'_2-zR'_1},\frac{C_2-z(s_2+r_2)-R'_2}{R_2-R'_2}\right)$$

This paper explores the gradual stability point between enterprises in the dynamic system when the government adopts the "incentive" strategy. By calculating the progressive stability point of the replication dynamic equation, the stable strategy point of the evolution game between enterprises in the process of green technology innovation is obtained, and the system evolution game is analyzed according to the change rule of the stable strategy point.

4. Numerical simulation analysis

In this paper, the evolution path of the game between the government, enterprise A and enterprise B and the position change of the equilibrium point are numerically calculated by Matlab, the game evolution process of the system is also analyzed. Considering the actual situation of parameters, the parameters are selected as follows:

$$R_1=2;R_2=2.5;R'_1=1;R'_2=1.5;r_1=2.5;r_2=3;C_1=4.35;C_2=5.95;s_1=0.5;s_2=1$$

Under the incentive of the government, the phase diagram of the game between enterprises A and B is shown in figure 1. It can be seen from the figure that A, P* and B constitute the demarcation of strategy selection in the game system. When the initial state of the game between firms A and B falls in the AP*BC region, the final result of the game will approach the strategy combination of innovation cooperation. On the contrary, the game result will be close to the strategy combination of non-innovation cooperation. According to the initial hypothesis and the revenue situation, the revenue of innovation cooperation between the two parties will be higher than that of the strategic combination without innovation cooperation. In order to promote innovation cooperation between the two parties, the stable point P* should be moved to the left or down, and the area of AP*BC should be increased, so as to increase the probability of innovation cooperation between the two parties.

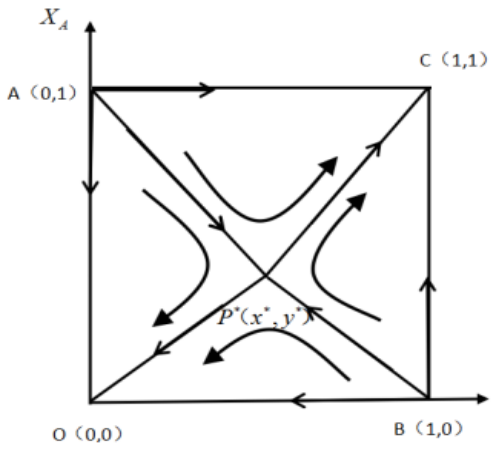

Figure 1: Evolutionary game phase diagram

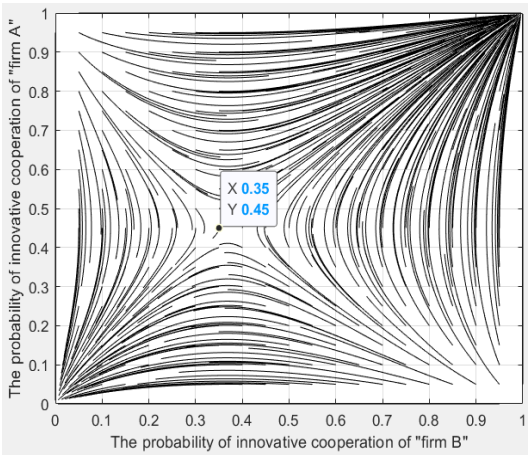

Figure 2: Simulation game results (Z=1)

In the simulation process, the innovation cooperation probability x, y∈ [0,1] of enterprises A and B is selected, and the minimum interval of change is 0.05. According to the calculation of strategy stability

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points, the coordinates of mixed strategy stability points are (0.35, 0.45), and the simulation game results are shown in figure 2. When the strategy stability point is determined, the strategy combination will gradually evolve into two outcomes: "innovation cooperation" and "non-innovation cooperation" according to the initial willingness of the two firms for innovation cooperation. The policy stability point P* is affected by basic parameters. When the single parameters R1, R2, R1 and R2 decrease, or the single parameters S1, S2, C1 and C2 increase, the policy stability point P* will move to the upper right and the area of regional AP*BO increases, which will increase the probability of non-innovation cooperation among enterprises. On the contrary, the strategic stable point P* will move to the lower left and the area of region AP*BC will increase, which will increase the probability of innovation cooperation between enterprises.

According to the replication dynamic equation calculated by Equations (7) and (8), different initial x and y values are selected. When the probability of firm A's initial choice of innovation is x=0.7, figure 3 and figure 4 show the evolution trend of the innovation cooperation probability of firm A and firm B, respectively. It can be seen from the game evolution that in the environment of government incentive and x=0.7, when y≥0.2, the game evolution strategy point is (1,1), and both enterprises A and B decisively choose the innovation cooperation strategy, and the trend becomes more obvious with the increase of y. When y < 0.2, the game evolution strategy point is (0,0), and both firms A and B choose the strategy of non-innovation cooperation.

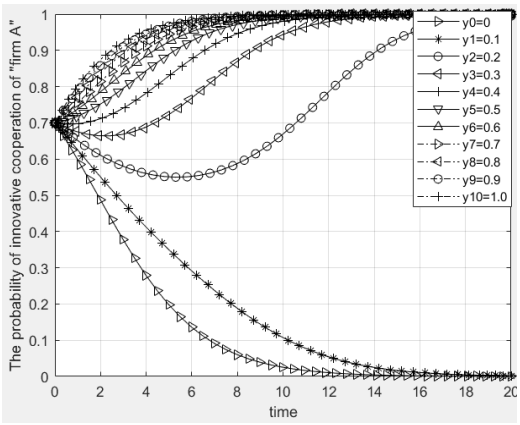

Figure 3: x=0.7 Game Evolution of Firm A

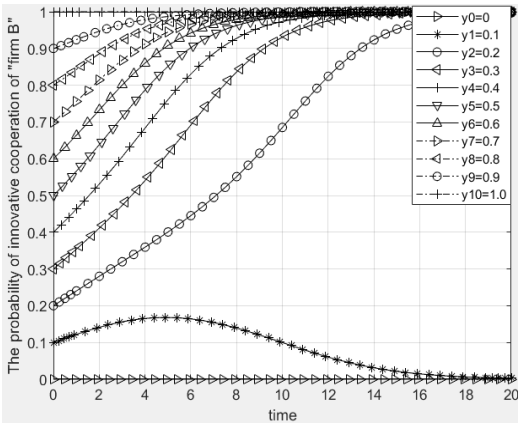

Figure 4: x=0.7 Game Evolution of Firm B

Combined with the results of the evolutionary game, when one of the two companies has a strong willingness to cooperate in innovation, as long as the other party has a certain willingness to cooperate in innovation, the final decision between the two companies is to choose the innovation cooperation strategy.

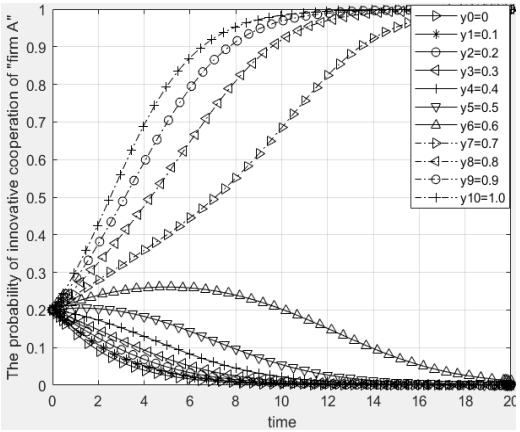

Figure 5: x=0.2 Game Evolution of Firm A

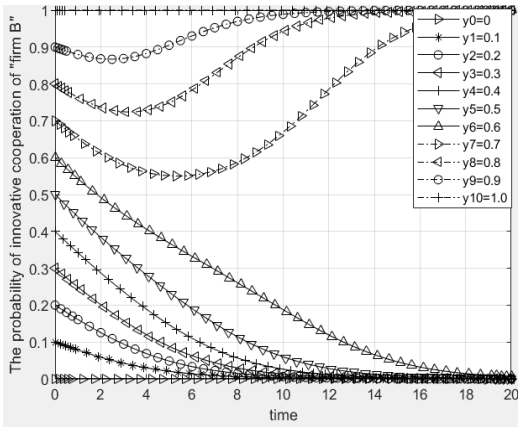

Figure 6: x=0.2 Game Evolution of Firm B

Figure 5 to figure 6 shows the evolution trend of the innovation cooperation probability between firm A and firm B when the initial probability of firm A choosing innovation is X =0.2. It can be seen from the game evolution that, with the government incentive and x=0.2, when y > 0.6, the game evolution strategy point is (1,1). Enterprises are more decisive in choosing the innovation cooperation strategy, and the trend becomes more obvious with the increase of y. When y≤0.6, all enterprises eventually choose

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the strategy of non-innovation cooperation, and the trend becomes more obvious with the smaller Y is. When y = 0.6, due to A low probability of innovation cooperation enterprise, enterprise B without hesitation, just to choose the strategy of cooperation innovation, at the same time, enterprises in order to cater to enterprise B willingness, tentatively promoted innovation cooperation will, eventually in the case of enterprise cooperation will B is declining, tend to choose not to innovate cooperation strategy.

From figure 5 and figure 6 learn that in the case of government incentives, the enterprise A and B will remain high innovation cooperation enthusiasm, but when A unilateral innovation cooperation active degree is not high, the other party is still inclined to choose cooperation innovation strategy, but in the face of innovation cooperation not stable income, and innovation cooperation between may face the risk of failure after input costs, They tend to choose conservative non-innovative collaboration strategies. For bounded rational participants, innovation cooperation is a risk-preference decision. When the cost of innovation is greater than the benefit, the decision maker will choose the risk-averse strategy, that is, to give up direct benefits and avoid bearing the uncertainty of innovation, which will lead to the final convergence of the game strategy choice to the point (0,0).

From figure 3 to figure 6, it can be seen that the evolution curves do not overlap, and the variation of the curve is related to the initial value of the probability of choosing innovation. The larger the initial state cooperation intention of enterprises, the more the system evolution tends to innovation cooperation, and the trend is more obvious. When the initial innovation willingness of both firms is greater than the equilibrium strategy point, the final result tends to the innovation cooperation strategy, otherwise, it tends to no innovation cooperation strategy. If the initial intention of innovation cooperation among enterprises is zero, the evolution results will tend to no innovation cooperation.

In order to prove that the incentive role of government plays an important role in the evolution of innovation cooperation between enterprises, we select the initial degree of government incentive as Z=0.9 for evolution, as shown in figure 7, and the strategy equilibrium points are (0.42,0.85). Figure 8 and figure 9 respectively show the evolution trend of the innovation cooperation probability between enterprises A and B when the government's incentive strategy probability Z=0.9 and the innovation probability of enterprise B is (0,1), and the initial value of innovation cooperation probability x=0.7 is selected by enterprise A. As can be seen from the figure, when y≥0.6, the evolution tends to the active collaborative innovation strategy. When y < 0.6, the game evolution strategy point is (0,0).

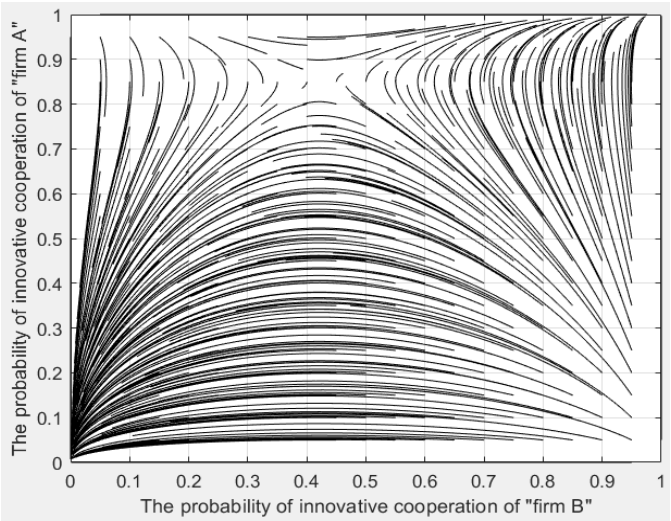

Figure 7: Simulation Game Results (Z=0.9)

By comparing figure 2 and figure 7, we can see that the government incentive measures have a very obvious impact on the innovation cooperation between enterprises, which directly affects the position of the stable point of the enterprise's game strategy. This is also confirmed by the comparison of figure 3 and figure 4 and figure 8 and figure 9. Under different government incentives, the evolution results of the same initial cooperation willingness among enterprises are completely different. When the level of government incentive decreases, the difficulty of innovation cooperation between enterprises increases greatly.

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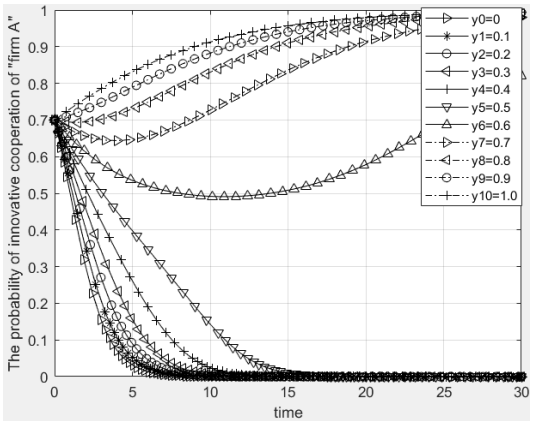

Figure 8: x=0.7 Game Evolution of Firm A

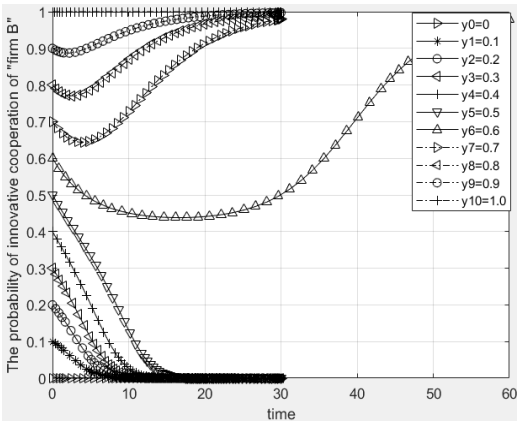

Figure 9: x=0.7 Game Evolution of Firm B

In addition, we can find from Figure 8 and Figure 9 that in the process of dynamic evolution game, it takes a long time for some enterprises to reach Nash equilibrium, and the time span for reaching decisions is relatively large, especially in the process of reaching collaborative innovation strategies. This situation indicates that, on the one hand, when the level of government incentive decreases, both enterprises will become more "cautious" in choosing the strategy of "innovation cooperation"; on the other hand, it also indicates that government departments should consider the time lag factor according to the specific situation when considering the intensity of innovation incentive.

5. Conclusions and policy recommendations

In this paper, an evolutionary game model between the government and two enterprises is established under the condition of bounded rationality of participants. The evolution path of the game and the position change of the equilibrium point are numerically calculated by Matlab, and the evolution of the competition and cooperation relationship between enterprises with different initial cooperation willingness under different incentive degrees of the government is analyzed. We found that in the process of green technology innovation among enterprises, a kind of interest coordination mechanism of "competition and cooperation game" is more reflected, and the cooperation willingness of enterprises will change due to the influence of the cooperation willingness of another enterprise. The initial cooperation willingness of enterprises has an important effect on the evolution results. When some enterprises have no cooperation on green technology innovation, it is often difficult to achieve inter-enterprise technology collaborative innovation. When enterprises get sufficient "incentives", they will be more inclined to green technology innovation collaboration strategy; The degree of government "incentive" plays an important role in the evolution of competition and cooperation relationship between enterprises. When the degree of government incentive decreases, the difficulty of realizing innovation cooperation strategy among enterprises increases greatly, which also shows the important position of government in the market environment. In order to promote resource cooperation and sharing and technology innovation collaboration among enterprises, and improve the level of green technology and green technology innovation ability in the market, we put forward the following countermeasures and suggestions:

First, strengthen the incentive degree of green technology innovation. In the process of green technology innovation cooperation, to participate in the main body of the profit and loss of appetite has obvious deviation, especially in the early stages of the collaborative innovation, more sensitive to the happening of the loss, there is the risk guard against the strong, the shortage of potential earnings forecasts, need government subsidies by increasing the technology innovation, to reduce the "incentive" measures such as tax, Improve the willingness of enterprises to carry out green technology innovation cooperation strategy; When the willingness of innovation cooperation is weak, it will take a long time to reach Nash equilibrium. The government should also consider the time lag factor according to the specific situation when considering the incentive strength.

Second, we should improve regulatory policies on collaborative innovation. To give full play to the relevant department of the control function of government, to the different nature of the enterprise, the reasonable rewards and punishments, play the role of "guardian", collaborative innovation to the enterprise green technology supervision, clear the direction of science and technology key, and in the process of collaborative innovation "opportunistic", "free rider" of participants to make corresponding

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punishment, to ensure the stability of green technology innovation environment.

Finally, promote enterprises to carry out technical exchanges. The government can strengthen the cooperation intention among heterogeneous enterprises and encourage enterprises to optimize the allocation of talents, equipment and other resources by building cooperation platforms for enterprises and improving cooperation subsidies for green technology innovation. By means of subsidies and market forces, enterprises with low level of green technology can be driven to reduce innovation costs and R&D cycles, so that enterprises can achieve the improvement of revenue and green level at a lower cost and risk, and form a benign collaborative innovation network.

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