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Research on Evolutionary Game of Collaborative Innovation Among High - Tech Industries - From the Perspective of Trust Relationship

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Abstract: In the era of 'Internet+' background, large flow, strong liquidity and short shelf life become the characteristics of information, technology specialization, increasing complexity, it is difficult for individual enterprises to grasp all the elements needed for successful innovation. In order to study the problem of collaborative innovation among high-tech inadustries, from the perspective of trust relationship between subjects, an evolutionary game model of collaborative innovation is constructed based on the technology intensity and spillover of high-tech industries, and the strategy evolution of subjects under market mechanism and government regulation is analyzed. The results show that innovation output and technology transformation ability promote collaborative innovation; r & D costs, 'free rider' income and so on hinder the collaborative innovation between industries; the influence of trust relationship and distribution coefficient on collaborative innovation depends on the situation. In addition, through simulation, it is found that the reward and punishment mechanisms of policies have their own advantages and disadvantages and complement each other, and the impact of supervision on collaborative innovation is diminishing marginal benefits. It is found that a reasonable policy combination can stimulate innovation potential more effectively. It is proposed that the strong technology spillover and mutual solubility between high-tech industries also lead to technology imitation. In the process of collaborative R & D, it is necessary to establish a solid strategic partnership, adhere to trust rationality, grasp the scale, and promote collaborative innovation. Under the principle of trust rationality, information sharing, cost sharing, and efforts to increase technology and information output can increase innovation benefits; the government should follow the economic law when making policies, rationally combine policies, make good use of the 'push' and 'pull' of the policy reward and punishment mechanism, promote collaborative innovation among industries, and enhance the driving force of innovation for economic development.

Keywords: Trust Relationship, High-Tech Industry, Collaborative Innovation, Evolutionary Game

1. Introduction

Innovation is the first driving force for industrial development. Only by providing high-quality technological innovation supply can we effectively support the transformation and upgrading of China's high-tech industry [1]. However, in the context of the 'Internet+' era, large flow, strong liquidity and short shelf life have become the characteristics of information. The specialization and complexity of technology are increasing, and it is difficult for a single enterprise to master all the elements needed for successful innovation [2]. Therefore, enterprises have to cooperate in a wider range of division of labor, joint product technology research and development, through the innovation network to obtain complementary resources needed for innovation and thus strengthen the ability of independent innovation [3]. The "14th Five-Year Plan for National Science and Technology Innovation" includes the support of scientific and technological innovation to lead the new development pattern and ideas into the catalogue of major issues. The high-tech industry has the characteristics of intellectual capital concentration and is an important force to break the barriers of scientific and technological achievements transformation and build a new pattern of innovation and development in China [4]. At the same time, the high-tech industry has the characteristics of high investment, breakthrough, spillover and strong technical mutual solubility [5]. The irrational trust of one party can easily lead to the 'free rider' behavior of the other party, the breakdown of cooperation and even the emergence of collaborative innovation in the whole industry. Therefore, it is of great practical significance to study the evolution law of collaborative innovation between high-tech industries from the perspective of trust relationship, which is of great practical significance to the emergence of collaborative innovation behavior and the improvement of innovation efficiency.

Collaborative innovation between industries to complementary resources as the premise, through mutual cooperation, learn from each other, resource sharing, the establishment of collaborative innovation system. In the research of inter-industry collaborative innovation, the relevant research points out that the degree of knowledge sharing [6], reasonable reward and punishment mechanism [7], cooperation mode [8] and other factors have a positive impact on the performance of collaborative innovation projects. In addition, Fan pointed out that the feedback mechanism of income and cost of cooperative innovation is conducive to curbing 'free-riding behavior' [9]. In terms of collaborative innovation research on trust, relevant scholars point out that trust is the core of collaboration. Trust relationship is conducive to enhancing the innovation ability of both parties, reducing the negotiation cost, supervision cost and other costs of collaborative parties [10-12], and promoting effective information sharing among all parties [13]. In addition, Amalya used case analysis to propose formal management rules to help maintain the trust relationship between enterprises [14], while Raluca pointed out that excessive reliance on trust will hinder the breakthrough innovation of enterprises [15], and Hong pointed out that inter-organizational trust and transaction income have a weak inverted U relationshipet [16].

In the research of collaborative innovation between high-tech industries, in addition to industrial development perspectives such as industrial synergy [17], industrial agglomeration [18], and industrial chain [19], Songbo analyzed the main factors affecting the technological innovation efficiency of high-tech industries through index decomposition, and pointed out that a sound cooperation model can optimize resource allocation and improve resource utilization efficiency and total factor productivity [20]. Liu Lanjian used entropy method to construct the index system, and pointed out that innovation policy should pay more attention to the coordinated development of high-tech industrial ecosystem [21]. Yuan Xumei found that market information feedback efficiency, knowledge transfer efficiency and multi-factor interaction can promote the level of collaborative innovation through system dynamics model and simulation [22].

From the existing research, few scholars have studied the collaborative innovation of high-tech industries from the perspective of game relationship, and the existing evolutionary game research on high-tech industries has not paid attention to collaborative innovation. In the evolutionary game research of collaborative innovation, there are few studies on the introduction of trust relationship. The few studies that consider the trust factor also do not consider the comprehensive impact of trust on the cost of collaborative innovation and the 'free ride' income. In view of this, under the assumption of bounded rationality, this paper constructs an evolutionary game model of collaborative innovation among high-tech industries from the perspective of trust relationship, discusses the dynamic evolution process of collaborative innovation strategy selection in high-tech industries, and considers the impact of government regulation on the choice of industrial collaborative innovation strategy.

2. Basic Assumptions and Model Building

2.1. Analysis of Innovation Subject

The main body of collaborative innovation in this paper is based on the premise of complementary resources, and two sub-groups of enterprises are randomly selected from the high-tech industry for multiple games. There is a certain technical and economic relationship between the two [23]. The two sides may be in the stage of calculating trust, that is, the degree of trust between the two sides is obtained through rational calculation and evaluation. It may also be in the stage of non-computational trust, that is, mutual recognition obtained through lasting interaction [16]. The two sides can continue the original ordinary cooperation, also can choose collaborative innovation mode, personalized research and development. Based on the assumption of bounded rationality, the two sides will analyze the benefits and costs according to the results of the previous game and choose the optimal strategy. In the process of collaborative innovation of high-tech enterprises, there are both the interaction of stock information and the generation of new information [24]. The sharing of stock information is affected by the degree of trust between the two sides of the game [25].

At the same time, new information belongs to R & D results, and the allocation ratio is set by the contract. That is to say, in this process, in addition to the basic benefits and costs, the two sides will also get the benefits brought by the research and development results, including the information generated in the whole process of research and development and the benefits brought by the technology and information finally formed by research and development. In the process of collaborative innovation, there are opportunistic behaviors, such as: one party withdraws from the collaborative innovation alliance when it obtains the resources it needs [26]. In addition, because high-tech enterprises have the characteristics of technology intensive and strong spillover, there is a risk of technology being imitated and copied, resulting in risk loss, but the protection of patented technology by law will reduce the risk loss of enterprises.

At the same time, due to the breakthrough characteristics of high-tech industry, the government will actively carry out macro-control, formulate relevant rewards and punishments to promote the emergence of collaborative innovation.

2.2. Fundamental Assumption

Hypothesis 1: Subject 1 and subject 2 are two sub-groups with complementary resources in high-tech enterprises, both of which are bounded rationality, and there is information asymmetry between them.

Hypothesis 2: The basic benefit of cooperation is r_i, $(i=1,2)$.

Hypothesis 3: When both parties choose collaborative innovation, the benefits are $\alpha_i p$ and $\beta_i(m_i+T_{ji}M_j)$. $\alpha_i p$ is the benefit brought by technology value-added, α_i is the technology transformation ability of both parties, and p is the amount of technology generated by collaborative innovation; $\beta_i(m_i+T_{ji}M_j)$ is the benefit of information obtained by collaborative innovation, β_i is the ability of information integration, m is the income after the distribution of new information generated by collaborative innovation, $T_{ji}M_j$ is the amount of information shared by both parties based on mutual trust in the process of collaboration, T_{ji} refers to the degree of trust of j to i, and $T_{ji}\in(0,1]$, M_j is the information stock of subject j. Let $A=\alpha_i p$, $B_i=\beta_i(m_i+T_{ji}M_j)$, $i,j=1,2$ and $i\neq j$.

Hypothesis 4: When both sides choose collaborative innovation at the same time, the cost required by collaborative innovation is $C_i\left(1-T_{ji}\right)$. Helping to gain the trust of the other party can result in cost savings. For example, if the sender of the information helps the receiver of the information to understand the information, the cost of information consolidation drops, $(i=1,2)$.

Hypothesis 5: In the case where one party chooses collaborative innovation and one party chooses non-synergy, the two parties do not involve the exchange of stock information, and the non-synergy party has a 'free-riding' behavior. The 'free-riding' income based on the degree of trust between the two parties is $N_i\left(1+T_{ji}\right)$.

Hypothesis 6: Risk loss is $Z_i\left(1-\gamma\right)$, Z_i is the loss due to technology spillovers and external opportunistic behavior, and γ is the legal protection of intellectual property. $\gamma\in[0,1]$, when $\gamma=1$, laws and regulations can play a completely protective role, when $\gamma=0$, it is completely the opposite.

Hypothesis 7: Assume that the proportion of ilndividuals choosing collaborative innovation in Group 1 is x, the proportion of individuals choosing non-collaborative innovation is $1-x$. The proportion of collaborative innovation in group 2 is y, and the proportion of individuals who choose non-collaborative innovation is $1-y$.

2.3. Analysis on Synergetic Development of High - Tech Industry Under Market Mechanism

According to the above assumptions, based on the principle of benefit maximization, subjects 1 and 2 choose whether to collaborative innovation. The payoff matrix is as follows:

Table 1. *The payoff matrix under market mechanism.*

Selection strategy	Synergism (y)	No coordination (1-y)
Synergism (x)	F_1, F_2	$r_1-C_1-Z_1\left(1-\gamma\right)$, $r_2+N_2\left(1+T_{12}\right)$
No coordination (1-x)	$r_1+N_1\left(1+T_{21}\right)$, $r_2-C_2-Z_2\left(1-\gamma\right)$	r_1, r_2

Note: $F_1=r_1+A_1+B_1-C_1\left(1-T_{21}\right)-Z_1\left(1-\gamma\right)$, $F_2=r_2+A_2+B_2-C_2\left(1-T_{12}\right)-Z_2\left(1-\gamma\right)$

Then the income of subject 1 when choosing collaborative innovation is:

$$U_{11}=\begin{Bmatrix} y\left[r_1+A_1+B_1-C_1\left(1-T_{21}\right)-Z_1\left(1-\gamma\right)\right] \\ +\left(1-y\right)\left[r_1-C_1-Z_1\left(1-\gamma\right)\right] \end{Bmatrix} = yA_1+yB_1+yT_{21}C_1+r_1-C_1-Z_1\left(1-\gamma\right) \quad (1)$$

The benefit of subject 1 when choosing non-collaborative innovation is:

$$U_{12}=y\left[r_1+N_1\left(1+T_{21}\right)\right]+\left(1-y\right)r_1=r_1+yN_1\left(1+T_{21}\right) \quad (2)$$

The average expected return of principal 1 is:

$$\overline{U_1}=xU_{11}+\left(1-x\right)U_{12} =\begin{Bmatrix} x\left[yA_1+yB_1+yT_{21}C_1+r_1-C_1-Z_1\left(1-\gamma\right)\right] \\ +\left(1-x\right)\left[r_1+N_1\left(1+T_{21}\right)\right] \end{Bmatrix} \quad (3)$$

The replication dynamic equation of the main body 1 is:

$$U\left(x\right)=dx/dt=x\left(U_{11}-\overline{U}_1\right)=x\left(1-x\right)\left(U_{11}-U_{12}\right) =x\left(1-x\right)y\begin{bmatrix} A_1+yB_1+yT_{21}C_1-C_1 \\ -Z_1\left(1-\gamma\right)-yN_1\left(1+T_{21}\right) \end{bmatrix} \quad (4)$$

Similarly, the benefits of subject 2's choice of 'synergy', 'non-synergy', and average expected benefits are:

$$\begin{aligned} U_{21} &= x\left[r_2 + A_2 + B_2 - C_2\left(1-T_{12}\right) - Z_2\left(1-\gamma\right)\right] \\ &\quad + \left(1-x\right)\left[r_2 - C_2 - Z_2\left(1-\gamma\right)\right] \\ &= xA_2 + xB_2 + xT_{12}C_2 + r_2 - C_2 - Z_2\left(1-\gamma\right) \end{aligned} \quad (5)$$

$$U_{22} = \left\{ \begin{array}{c} x\left[r_2 + N_2\left(1+T_{12}\right)\right] \\ +\left(1-x\right)r_2 \end{array} \right\} = r_2 + xN_2\left(1+T_{12}\right) \quad (6)$$

$$\overline{U_2} = yU_{21} + \left(1-y\right)U_{12} = y\left(\begin{array}{c} xA_2 + xB_2 + xT_{12}C_2 \\ +r_2 - C_2 - Z_2\left(1-\gamma\right) \end{array} \right) + \left(1-y\right)\left[r_2 + N_2\left(1+T_{12}\right)\right] \quad (7)$$

The replication dynamic equation of subject 2 is:

$$\begin{aligned} U\left(y\right) &= dy/dt = y\left(U_{21} - \overline{U}_2\right) = y\left(1-y\right)\left(U_{21} - U_{22}\right) \\ &= y\left(1-y\right)\left(\begin{array}{c} xA_2 + xB_2 + xT_{12}C_2 - \\ C_2 - Z_2\left(1-\gamma\right) - xN_2\left(1+T_{12}\right) \end{array} \right) \end{aligned} \quad (8)$$

According to the above $U\left(x\right)=0$, $U\left(y\right)=0$ the two sides of the game on $R=\left\{\left(x,y\right)\middle|0\le x\le 1, 0\le y\le 1\right\}$ can obtain five local equilibrium points: $O\left(0,0\right)$, $A\left(0,1\right)$, $B\left(1,1\right)$, $C\left(1,0\right)$, $D\left(x^*,y^*\right)$, where $x^* = \dfrac{C_2 + Z_2\left(1-\gamma\right)}{A_2 + B_2 + T_{12}C_2 - N_2\left(1+T_{12}\right)}$, $y^* = \dfrac{C_1 + Z_1\left(1-\gamma\right)}{A_1 + B_1 + T_{21}C_1 - N_1\left(1+T_{21}\right)}$. The stability of the system equilibrium point is analyzed by using the local stability of the Jacobian matrix. When x^* and y^* are on the R plane, that is $0 < c_i + Z_i\left(1-\gamma\right) < \left(\begin{array}{c} A_i + B_i + T_{ij}C_i \\ -N_i\left(1+T_{ij}\right) \end{array} \right)$, $i=1,2$. The five equilibrium points of the system are shown in Table 2:

Table 2. *Stability analysis of local equilibrium point of system evolution under market mechanism.*

Point of equilibrium	$Det\left(J\right)$	$Tr\left(J\right)$	Stability of equilibrium point
$O\left(0,0\right)$	+	-	ESS
$A\left(1,0\right)$	+	+	Destabilization
$B\left(1,1\right)$	+	-	ESS
$C\left(0,1\right)$	+	+	Destabilization
$D\left(x^*,y^*\right)$	-	0	Saddle point

As can be seen from Table 2, point O and point B are stable points, and their corresponding strategies are (synergistic, synergistic) and (non-synergistic, non-synergistic) Pareto optimal results, A and C are unstable points, D is saddle point. From Table 2, the phase diagram of the dynamic process of evolutionary game under market mechanism can be drawn, as shown in Figure 1 below:

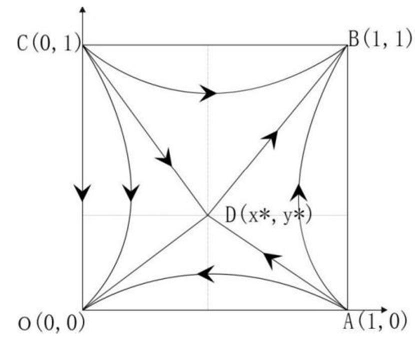

Figure 1. *Phase diagram of evolution of two sides in game under market mechanism.*

It can be seen from Figure 1 that after a long-term game, regardless of the initial decision of both parties, they will eventually evolve to the two stable states of (synergy, synergy) and (non-synergy, non-synergy). The probability that the two sides of the game finally choose the evolutionary strategy is related to the relative size of the regional OADC area S1 and the regional ABCD area S2. The larger the area of S1 is, the greater the probability that both sides of the game choose (non-cooperative, non-cooperative) strategy is. On the contrary, the larger the area of S2 is, the greater the probability that both sides of the game choose (cooperative, cooperative) strategy is. According to the influence factors of area change, the system evolution trend can be analyzed.

$$S_1 = \frac{1}{2}\left(x^* + y^*\right) = \frac{1}{2}\left(\begin{array}{c} \dfrac{C_2 + Z_2\left(1-\gamma\right)}{A_2 + B_2 + T_{12}C_2 - N_2\left(1+T_{12}\right)} + \\ \dfrac{C_1 + Z_1\left(1-\gamma\right)}{A_1 + B_1 + T_{21}C_1 - N_1\left(1+T_{21}\right)} \end{array} \right) \quad (9)$$

Corollary 1: Under the market mechanism, the probability of selecting collaborative innovation among high-tech industries is inversely related to the cost of collaborative innovation.

Proof: $\dfrac{\partial S_1}{\partial C_1} = \dfrac{A_1 + B_1 - N_1\left(1+T_{21}\right) - T_{21}Z_1\left(1-\gamma\right)}{2\left[A_1 + B_1 + T_{21}C_1 - N_1\left(1+T_{21}\right)\right]^2}$,

on the $R=\left\{\left(x,y\right)\middle|0\le x\le 1, 0\le y\le 1\right\}$ plane,

$\left\{ \begin{array}{c} A_1 + B_1 - N_1\left(1+T_{21}\right) \\ -T_{21}Z_1\left(1-\gamma\right) \end{array} \right\} > 0$, so $\dfrac{\partial S_1}{\partial C_1} > 0$. Similarly, $\dfrac{\partial S_1}{\partial C_2} > 0$,

so S_1 increases monotonically with respect to C_i, and the probability of the evolution of the main decision to collaborative innovation decreases.

High-tech industry has the characteristics of technology intensive, technology R & D cycle is longer, R & D investment is slow. Therefore, the higher the cost of the subject in collaborative innovation, the lower the probability of both parties choosing collaborative innovation. The trust relationship between the subjects helps to save R & D costs, improve R & D revenue, and has a certain inhibitory effect on the obstacles brought by costs in collaborative innovation.

Corollary 2: Under the market mechanism, the probability of choosing collaborative innovation among high-tech industries is negatively correlated with risk loss and positively correlated with legal protection.

Proof: $\frac{\partial S_1}{\partial Z_1}=\frac{1-\gamma}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]}$, $1-\gamma>0$, so $\frac{\partial S_1}{\partial Z_1}>0$, similarly available, $\frac{\partial S_1}{\partial Z_2}>0$. S_1 is an increasing function of with respect to. $\frac{\partial S_1}{\partial \gamma}=\left(\frac{-Z_2}{2[A_2+B_2+T_{12}C_2-N_2(1+T_{12})]}+\frac{-Z_1}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]}\right)$, risk loss promotes the evolution of subject decision to non-collaborative innovation. Obviously $\frac{\partial S_1}{\partial \gamma}<0$, S_1 is a decreasing function of γ, the law on the protection of intellectual property rights to promote the emergence of collaborative innovation between industries.

Compared with other industries, the spillover effect of knowledge and technology in high-tech industry is obvious, and the potential loss caused by risk reduces the R & D willingness of the subject. However, with the improvement of relevant laws and regulations, the potential risk becomes smaller, which increases the willingness of the subject to choose collaborative innovation.

Corollary 3: Under the market mechanism, the probability of choosing collaborative innovation among high-tech industries is positively correlated with technology transformation ability and the amount of technology generated by collaborative innovation.

Proof: $\frac{\partial S_1}{\partial \alpha_1}=\frac{-P[C_1+Z_1(1-\gamma)]}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]^2}$, $\frac{\partial S_1}{\partial \alpha_1}<0$, similarly, $\frac{\partial S_1}{\partial \alpha_2}<0$, so S_1 is a decreasing function of α_i, the probability of both sides' decisions evolving to collaborative innovation increases.

$\frac{\partial S_1}{\partial P}=\frac{-\alpha_1[C_1+Z_1(1-\gamma)]}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]^2}$, $\frac{\partial S_1}{\partial P}<0$, S_1 is a decreasing function of P, that is, the probability of both sides choosing collaborative innovation increases with the increase of the amount of technology.

In the high-tech industry, technology is the main achievement of collaborative innovation. The transformation ability of technology determines how much the subject benefits from it, thus affecting the subject's willingness to collaborative innovation.

Corollary 4: Under the market mechanism, the probability of collaborative innovation among high-tech industries is positively correlated with the ability of information integration and the generation of information.

Proof: $\frac{\partial S_1}{\partial m_1}=\frac{-\beta_1[C_1+Z_1(1-\gamma)]}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]^2}$, $\frac{\partial S_1}{\partial m_1}<0$, Similarly, $\frac{\partial S_1}{\partial m_2}<0$, so S_1 is a decreasing function of m_i. The probability that both sides of the game choose collaborative innovation increases with the amount of information it produces. $\frac{\partial S_1}{\partial \beta_1}=\frac{-(m_1+T_{21}M_2)[C_1+Z_1(1-\gamma)]}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]^2}$, similarly, $\frac{\partial S_1}{\partial \beta_2}<0$, so S_1 is therefore a decreasing function of β_i, information integration capabilities to promote the main body towards the evolution of collaborative innovation.

In the era of 'Internet+', information is an important strategic resource. The amount of information available and the ability to integrate information will promote collaborative innovation between industries. At the same time, the influence of information integration ability on collaborative innovation is affected by the degree of trust and the information stock of the other party.

Corollary 5: Under the market mechanism, the probability of selecting collaborative innovation among high-tech industries depends on the degree of trust between the two sides, and is positively correlated with the information stock of both sides.

Proof: $\frac{\partial S_1}{\partial T_{21}}=\frac{(\beta_1 M_2+C_1-N_1)[C_1+Z_1(1-\gamma)]}{2[A_1+B_1+T_{21}C_1-N_1(1+T_{21})]^2}$, when $\beta_1 M_2+C_1>N_1$, $\frac{\partial S_1}{\partial T_{21}}<0$, the probability that the system evolves to $B(1,1)$ increases. Conversely, when $\beta_1 M_2+C_1<N_1$, $\frac{\partial S_1}{\partial T_{21}}>0$, the probability that the system evolves to $O(0,0)$ increases. Similarly, the relationship between S_1 and T_{12} is similar to that between S_1 and T_{21}. Therefore, when $\beta_i M_j+C_i>N_i$, S_1 is a decreasing function of T_{ji}, and the probability of the subject choosing collaborative innovation increases with the increase of the degree of trust between the two parties. On the contrary, when $\beta_i M_j+C_i<N_i$, S_1 is an increasing function of T_{ji}. When the

degree of trust between the two sides continues to deepen, the trust rationality gradually loses, and the 'free ride' income will exceed the benefits brought by the trust relationship between the two sides. Under the conditions of asymmetric trust and maximizing the pursuit of benefits, the probability of both sides of the game choosing collaborative innovation decreases. $\frac{\partial S_1}{\partial M_1} = \frac{-\beta_2 T_{12}\left[C_2 + Z_2\left(1-\gamma\right)\right]}{\left[A_2 + B_2 + T_{12}C_2 - N_2\left(1+T_{12}\right)\right]}$, obviously, $\frac{\partial S_1}{\partial M_1} < 0$. Similarly, $\frac{\partial S_1}{\partial M_2} < 0$, so S_1 is a decreasing function of M_j, the system to the premise of complementary resources, the greater the stock of information, the more obvious complementary advantages of both sides, the greater the probability of both sides choose collaborative innovation game.

In addition, the trust relationship and technology integration ability of both parties affect the probability evolution speed of the subject's choice of collaborative innovation.

Corollary 6: Under the market mechanism, the probability of choosing collaborative innovation among high-tech industries is inversely related to the free-riding profit.

Proof: $\frac{\partial S_1}{\partial N_1} = \frac{\left(1+T_{21}\right)\left[A_1 + B_1 + T_{21}C_1 - N_1\left(1+T_{21}\right)\right]}{2\left[A_1 + B_1 + T_{21}C_1 - N_1\left(1+T_{21}\right)\right]^2}$, obviously $\frac{\partial S_1}{\partial N_1} > 0$. Similarly, $\frac{\partial S_1}{\partial N_1} < 0$, so S_1 is an increasing function of N_1, that is, the probability that both sides of the game choose collaborative innovation decreases as the free-riding revenue increases.

At the same time, from the perspective of 'free rider', as the trust relationship progresses, the probability of both parties choosing collaborative innovation decreases faster. In the high-tech industry with strong spillover, due to the strong mutual solubility of knowledge and technology within the industry, the threshold of 'free rider' is lower, while the R & D cost is higher. With the increase of 'free rider' income, the probability of collaborative innovation is lower.

3. Example Analysis and Numerical Simulation

Through the above analysis of the impact of various elements on the choice of collaborative innovation strategy, to further demonstrate the evolution of collaborative innovation strategy between high-tech industries. This paper uses Matlab software to simulate and compare the strategy evolution of collaborative innovation under the market mechanism and the joint action of government and market, and describes the necessity of government macro-control when the market mechanism fails. At the same time, the influence of government reward and punishment mechanism on the evolution of collaborative innovation strategy is analyzed. Air China Guizhou Liyang Aviation Power Co., Ltd. and Beijing Zhongdian Xingfa wholly-owned subsidiary signed the "Strategic Cooperation Framework Agreement " on February 18, 2019. Based on the principle of "demand traction, collaborative innovation and common development," the two sides conduct exchanges in various aspects such as technical support, project declaration and technical research on the basis of cooperation, carry out in-depth cooperation in scientific research and project development, and jointly promote military-civilian integration in the field of smart city technology. It is assumed that China Aviation Guizhou Liyang Aviation Power Co., Ltd. is the main body 1, and Beijing Zhongdian Xingfa wholly-owned subsidiary is the main body 2. Drawing on previous research and the opinions of relevant experts, the relevant data are adjusted on the premise of striving to generalize the conclusions. The simulation data is set as table 3.

3.1. The Impact of Collaborative Innovation Revenue and Cost on the Evolution of Collaborative Innovation Strategy

Collaborative innovation achieves reciprocal knowledge sharing within the main elements of innovation [27]. This reciprocal relationship is based on the satisfaction of the cooperative subject with the expected benefits. Therefore, cost and benefit are important factors affecting collaborative innovation. According to the previous derivation, the evolution trend of collaborative innovation strategy is negatively correlated with cost and positively correlated with income. Accordingly, this paper further studies the impact of revenue and cost on collaborative innovation strategy choice with or without government incentives. Here, assuming that the values of A and B remain unchanged, without government incentives and subsidies, the income-cost ratios are 3.33, 4, 5, and 6.67, respectively. The simulation results are shown in Figure 2. When there are government incentives and subsidies, the government incentive amount is 10, and the income cost ratio is 1.54, 1.67, 1.82 and 2 respectively. The simulation results are shown in Figure 3.

It can be seen from Figure 2 and Figure 3 that regardless of government incentives, collaborative innovation income promotes the evolution of the subject to collaborative innovation, while collaborative innovation costs promote the evolution of the subject to non-collaborative innovation, which verifies Inference 1, Inference 3, and Inference 4. At the same time, under the no government incentive policy, the threshold of the income cost ratio is between 5 and 6.67, while under the government's incentive policy, the threshold of the income cost is between 1.82 and 2, and under the government incentive policy, the subject evolves to the collaborative innovation strategy faster, indicating that the government's incentive policy increases the subject's income and reduces the cost, which has a strong role in promoting the emergence of collaborative innovation. Based on this strategic cooperation agreement, Beijing

Zhongdian Xingfa and Liyang Power fully integrate the advantages of technology and talents, reduce innovation costs, promote technological cooperation and technological innovation, cultivate new industrial growth points, and enhance corporate profitability.

Table 3. *Simulation parameter assignment (i, j=1, 2, i≠j).*

Parameter	α_1	α_1	p	β_1	β_2	m_i	T_{ji}	M_i	C_1	C_2
Implication	**technology commercialization**		**Technical quantity**	**information integration ability**		**information gain**	**trust degree**	**informatio n stock**	**Collaborative innovation cost**	
Assignment	1	0.9	10	1	0.9	4	4	10	9	10

Parameter	N_1	N_2	Z_1	Z_2	γ	L	ω	ε	D
Implication	**Free-riding gains**		**risk loss**		**Legal protection**	**Financial incentive amount**	**partition coefficient**	**supervision strength**	**fine**
Assignment	5	6	4	3	0.6	10	0.5	0.5	4

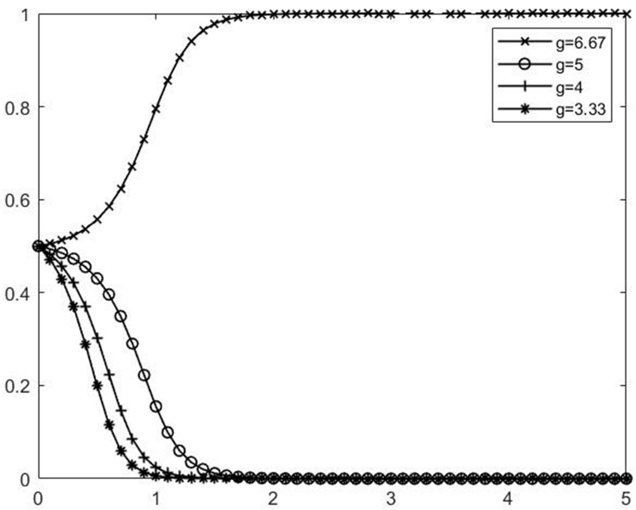

Figure 2. *Evolution path of strategy under different income and cost without government incentive.*

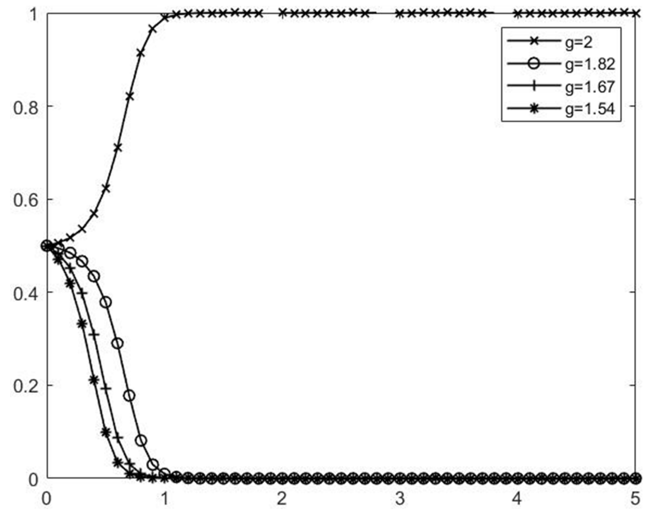

Figure 3. *Strategy evolution path under different income and cost with government incentives.*

3.2. The Impact of Financial Incentives on the Evolution of Collaborative Innovation Strategy

The high-tech industry technology innovation investment cost is high, the R & D cycle is long, the capital recovery period is long, the heavy innovation burden reduces the collaborative innovation willingness of the subject, and the financial incentive is particularly important for collaborative innovation. At the same time, in order to compare the similarities and differences between the government reward and punishment mechanism, the fine is set to 0, the amount of financial incentives are taken: 9, 10, 11, 12, the simulation results are shown in Figure 4.

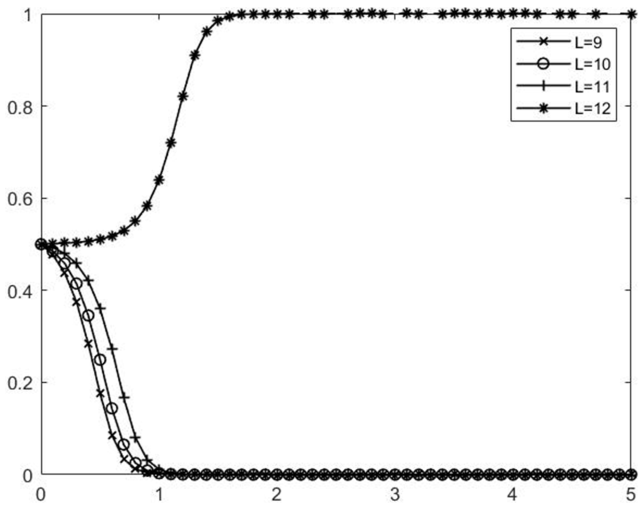

Figure 4. *Evolutionary path of collaborative innovation strategy under different fiscal incentives.*

From Figure 4, we can see that in the unsupervised situation, the threshold of fiscal incentive amount is between 11 and 12. The long-term nature of policy, the disorder of market and the existence of resource mismatch restrain the speed of government incentive policy to a certain extent. However, after a certain period of strategy evolution, collaborative innovation behavior will still emerge rapidly. In order to further explore the importance of government supervision, the financial incentive amount is set to 10 and the government fine is set to 0.

3.3. The Influence of 'Free Riding' Profit and Risk Loss on the Evolution of Collaborative Innovation Strategy

Due to the continuous cost input in the innovation process of high-tech industries, it is easy for participants to withdraw from the innovation alliance after obtaining the resources they need to obtain 'free ride income'. Technological achievements are the main output of high-tech industries, and high-tech industries have the characteristics of spillover and strong technology intersolubility, so technology has the risk of being imitated, reducing the willingness of innovation. Based on the important influence of 'free-riding' gains and risk losses on the evolution of collaborative innovation strategy, the two are simulated. The free-riding gains of agent 1 are set as: 3, 4, 5, 6, and the risk losses are set as: 1, 2, 3, 4. The simulation results are shown in Figures 5 and 6.

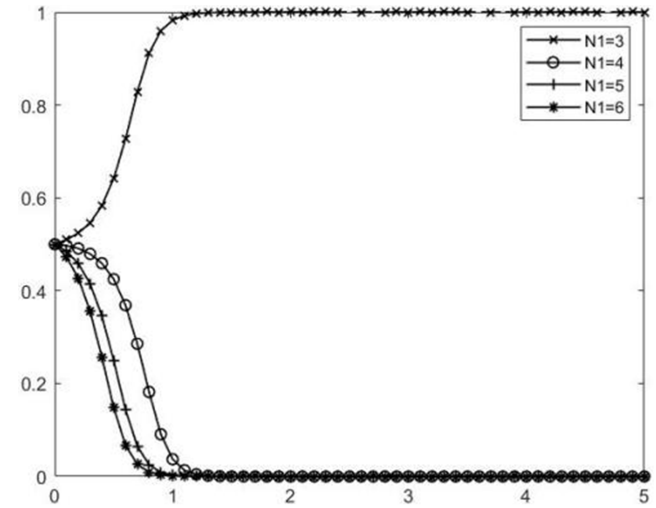

Figure 5. *Impact of 'free riding' gains on strategy evolution.*

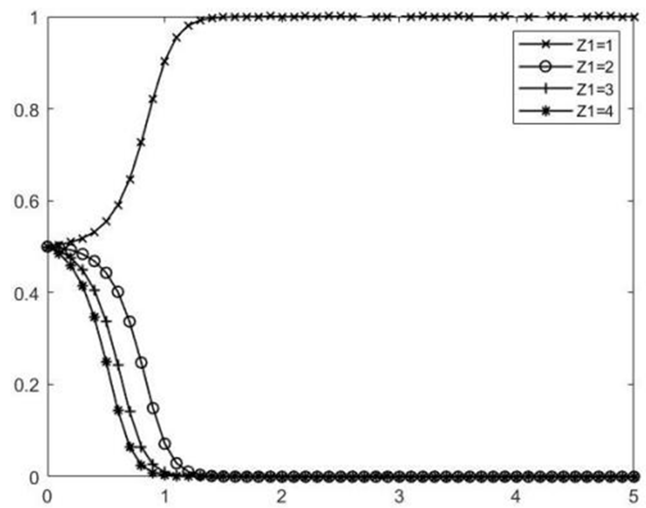

Figure 6. *Impact of risk loss on evolution of collaborative innovation strategy.*

From Figure 5, it can be seen that without government supervision, with the increase of 'free rider' income, the strategy evolves to non-collaborative innovation, which proves Corollary 6, and there is a threshold between 3 and 4 for 'free rider' income. From Figure 6, it can be seen that the choice of collaborative innovation strategy of enterprises is inversely related to risk loss, and there is a threshold between 1 and 2 risk loss. Beijing Zhongdian Xingfa and Liyang Power have carried out in-depth cooperation in technology research, project development, product promotion and other aspects, promoted the integration and development of key business and industrial chain between the two sides, formed a community of shared interests, strong strategic partnership, small possibility of default, fast response to risks and strong ability to resist risks.

4. Conclusions and Suggestions

Based on the evolutionary game theory, this paper analyzes the influencing factors of collaborative innovation among high-tech industries and the combination effect of government policies under the consideration of trust. By constructing the evolutionary game model and using Matlab to simulate, the results show that:

(1) Technological transformation ability, technological achievements, information integration ability, the amount of information generated by innovation, information stock, legal protection, financial incentives, government supervision and fines promote the emergence of collaborative innovation behavior, while the cost of collaborative innovation, 'free rider' income and risk loss inhibit the emergence of collaborative innovation behavior. In addition, the impact of trust and distribution coefficient on collaborative innovation depends.

(2) Government incentive policies can reduce the burden of enterprise innovation, increase innovation revenue and promote collaborative innovation. Government supervision can restrain 'free rider' behavior, enhance law enforcement, reduce risk loss and resource mismatch, and ensure the effective implementation of incentive policies.

(3) Under the established incentive policy, the influence of the government's supervision on collaborative innovation is diminishing marginal benefit, gradually reaching saturation.

Based on the above research conclusions, this paper puts forward the following policy recommendation:

(1) The technology spillover and mutual solubility between high-tech industries are strong, which also leads to technology imitation. In the process of collaborative R & D, we should not only establish a strong strategic partnership, but also adhere to trust rationality, grasp the scale and promote collaborative innovation;

(2) Under the principle of trust rationality, information sharing, cost sharing, and efforts to increase technology and information output can increase innovation benefits;

(3) When formulating policies, the government should follow the economic laws, rationally combine policies, make good use of the "push" and "pull" of the policy reward and punishment mechanism, promote collaborative innovation among industries, and enhance the driving force of innovation for economic development.

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