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Promoting Strategy of Chinese Green Building Industry: An Evolutionary Analysis Based on the Social Network Theory

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ABSTRACT Developing green building industry (GBI) is an effective way to promote sustainable economic development, realize energy savings, and reduce emissions. In this paper, an evolutionary game model is developed to examine the interactions between technology, knowledge transfer, and enterprises' behaviors in innovation networks. Through analysis of the evolutionary trend of the game, the cost of cooperative innovation is found to be an important factor that determines the evolutionary stable state or strategy (ESS). The government grant and financial support are deemed critical to promote the development of green building products (GBP). The government supervision, government procurement, and R&D are important for the GBI.

INDEX TERMS GBI, evolutionary game, government grant, financial support, social network.

I. INTRODUCTION

In this low-carbon emission era, conflicts between environmental management and economic development have intensified, thus leading to many problems [1]. At present, the world is facing many serious problems such as increased climate change, energy supply and demand contradictions, and environmental degradation. With the rapid development of the building industry, the usage of traditional building industry has become the most significant contributor to global climate change and environmental pollution in many countries [2]. Not only has traditional building industry caused pollution issues, but it will waste a lot of energy in the process. Buildings play an important role in causing global green-house gases (GHG) emissions and they are responsible for more than 40% of total GHG emissions. Some research institutions conducted a survey which also reported that buildings account for nearly 70% of GHG emissions in Hong Kong and up to 40% of total energy consumption [3]. Accordingly, reducing GHG emissions produced form the entire building life cycle has become a major concern in the construction industry.

In the last decade, the field of construction has been identified as key to achieving energy and emission reduction goals [4]. This area of focus by the government was embodied in the Decision to Enforce Energy Conservation and the Comprehensive work program on Energy Conservation and Pollution Reduction. As it is an effective way to mitigate the energy and environment crisis in the field of construction. Edmonds and Jordaan found that developing and using advanced technologies and knowledge as a fundamental way of addressing these issues [5], [6]. This situation can be resolved with GBI that have the characteristics of energy conservation and emissions' reduction [7], [8]. The GBI is far more eco-friendly in urban areas compared with traditional alternatives [9], which helps facilitate the country's ability to reach environmental regulation goals, cope with energy challenges, and sustain GBI by providing more diversified energy resources [10]. Thus, developing and promoting advanced technology and knowledge in the GBI will help solve many issues. A lot of policies have been issued by the central and local governments to promote the adoption of GBI,

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but these have had limited effect. There are two reasons: on one hand, consumer interest in GBI products is relatively low and a large proportion of the respondents have a''wait and see''attitude. Consumers are unsure about GBI products performance, with safety, reliability range, cycle life; on the one hand, the incentive policies succeeded in promoting GBI products sales. However, GBI market share remains low. GBI face more barriers, such as a series of technology problems including power, infrastructure, material, R&D and so on, which increase the cost of enterprises. Then, we need to solve more barriers, fund innovation activities, and encourage more enterprises choose to produce the GBI products. Therefore, this study focused more on barriers from government grant, financial policy, enterprises functional and cost prospective, which are important to the industry development of greening building.

The GBI has the characteristics of having a multi-disciplinary cross-integrated workforce, innovative input and risk, high technical complexity, and market uncertainty. Thus, building an innovation network for funding innovation activities is necessary. An innovation network is a structure that consists entirely of individuals (or organizations). Researchers call them ''nodes'' or ''actors''; one or more specific types of relationships, such as cooperation, trust, common interest, knowledge or technology, tie (connect, include strong tie and weak tie) these nodes together. Innovation network analyses explain inter-organizational relationships using social network theory, that is, the concept of nodes and ties (also edges, links, or connections). A node with many edges has multiple alternatives for meeting specific needs, which mediate its dependence on other organizations. Researchers distinguish between different levels of strength in the links of an innovation network, they commonly define ''strong and weak'' ties. Stronger links represent closer friendships and more frequent interactions. In an innovation network, if a node has more connections compared to others in the innovation network, that node is in an advantageous position, we call it as ''focal node''/ ''focal enterprise'' [11]. On the other side, researchers observe weak edges and when the structure of inter-group relationships is poorly outlined, that node is considered to be a ''marginal node''/ ''marginal enterprise'' [12], [13]. The focal and marginal enterprises have advantages such as bargaining power, the possibility of attracting the attention of other nodes, and having a greater effect on other players [14]. Much academic research has been conducted on innovation networks. Cooperation innovation establishes a crucial aspect in the study of innovation networks, where interactions among individuals influence the success of the community [15]. Apicella *et al.* [16] studied the interactions among individuals (include the structure, properties and dynamics of innovation networks) affected the emergence of cooperation and its evolutionary dynamics. Orman *et al.* [17] analyzed the evolution of the nodes in innovation networks. Du *et al.* [18] considered a complex network perspective on interrelations and evolution features. Paksoy *et al.* [19] studied an innovation network problem from the supply chain company, which was related to trade-offs between operational and environmental performance measures. In open market economics, network externalities affect the diffusion of technology and knowledge [20], [21]. Mitra *et al.* [22] studied the effects of government grants, and shown that different subsidy strategies had different effects on enterprises' capacity to absorb and transform new knowledge and technology. Codani *et al.* [23] considered the responses of financial institutions. They came to the conclusion that financial institution's subsidies on enterprises dramatically reduce enterprises' costs; therefore, enterprises are more likely to fund innovation activities. In-network researchers should evaluate individuals' actions not only in isolation but also in relation to others' reactions to those actions. On the one hand, enterprises deliberately design integrated networks; on the other hand, innovation networks emerge because of the collective actions of enterprises pursuing their individual profits. The important forms of an innovation network are the distributed portfolios, the exploration and exploitation of knowledge or technology, and the role of a network's position on knowledge production and technology practices [24].

The above-mentioned research mainly considered GBI policies and innovation network structures, evolutions, and characteristics. Research on innovation networks' focal and marginal enterprises' behaviors are sparse. For these reasons, based on innovation networks theory [25], this paper creatively introduces an equilibrium analysis of the game between focal and marginal enterprises, and two alternatives considered: fund/join or not fund/not join for enterprises. With an evolutionary game model has been developed to provide important research in the subject area [1], [26], [27]. Many different categories of relationships and connections are studied such as: government and financial actions, whether a fund strategy can be converged, its converge speed, and whether marginal enterprises would like to follow and join. To verify the theoretical results, realistic simulation experiments are conducted with meaningful results. The results and conclusions could serve as a useful guide for governments and financial institutions for making relevant policy and strategy decisions for enterprises. It is very beneficial for focal and marginal enterprises to choose best-response to promote sustainable economic development.

II. METHODOLOGY

In the long-term process of GBI innovation network development, enterprises need to game with each other several times. They have different strategy based on their network characteristics. Enterprises are not in complete rational consciousness. They present strong or poor abilities in a rational sense, analysis, and accurate identification and judgment of behavior, which cannot result in the best-response at the beginning. Assuming that the relationship is independent, we can analyses the evolution of enterprises behaviors by building the game model [28]. Evolutionary game theory includes Evolutionary Stable Strategy (ESS) and Replicator Dynamic. Our study examines the ESS and the influence of

the system evolution caused by government grant, financial support, and the cost of cooperative innovation under the circumstance of the mechanism.

In order to explore the influence of various parameters exiting in the process of the game on the final ESS, the following basic explanations are given:

(1) Focal enterprises "f" and marginal enterprises "m" are limited rational players, and their strategy selection space is (fund/join or not fund/not join).
(2) Supposing the probability of focal enterprises choosing to fund an innovation strategy is x, and the probability of choosing not to fund an innovation strategy is *1-x*. Then, if the proportion of marginal enterprises that select the join strategy is y, and the proportion selecting not to join is *1-y*. The state of the system evolution can be represented by (x, y) on available area $[0, 1]\times[0, 1]$.
(3) Focal enterprises m and marginal enterprises f decide to adopt their own strategy based on the benefits. The information of the dynamic decision-making process is incomplete for both sides of the game.

Based on the above basic points, the parameters and the relevant symbol conventions are shown in Symbol and Definition.

This model considers a system that comprises two representatives: focal and marginal enterprises. The focal enterprises have strong ties in an innovation network, and they can easily promote any type of information, especially knowledge and technological information, flow by means of their direct relationships. A strong relationship between nodes eliminates trust issues. The focal enterprises have two strategies: fund or not fund. If they fund an innovative activity, which can easily promote trust between players, and other enterprises throughout the network will rapidly imitate their innovation. If they do not fund the innovation, the technology and knowledge may not move through the network effectively. Marginal enterprises have weak ties within the network but still have the possibility to acquire and provide new knowledge to the innovation network. they also have two strategies: joining innovation activities or not joining them. The government provides support such as government grant (include subsidies). Financial institutions provide financial support (such as green credit, green bonds, green insurance and green fund).

If enterprises choose to cooperate, both sides can gain not only the benefits under the condition of normal innovation network, but also some extra income (include additional income, tax incentive, government grant and financial support). However, they must pay a cost for cooperation. If focal enterprises choose not fund or marginal enterprises choose not join, then the betraying enterprises will suffer greater losses [1]; also in this situation, if focal enterprises choose fund or marginal enterprises choose join, then they will gain some extra income from the government and financial institution. If the two sides are in not fund or not join, then they can only benefit from normal market situation. The game payment matrix is shown in Table 1.

TABLE 1. Payoff matrix of model.

Focal Enterprise	Marginal Enterprise	
	Join (y)	Not Join (1-y)
Fund (x)	U_{f1}, U_{m1}	U_{f2}, U_{m2}
Not Fund ($1-x$)	U_{f3}, U_{m3}	U_{f4}, U_{m4}

Assumption 1: When focal enterprises and marginal enterprises cooperate, namely, focal enterprises fund and marginal enterprises join innovation activities, the gains of focal enterprises and marginal enterprises are as follows:

$$U_{f1} = K_1 I_1 - C_1 + R_1 + T_1 + \alpha G + \beta F_1 \quad (1)$$
$$U_{m1} = K_2 I_2 - C_2 + R_2 + T_2 + (1-\alpha) G + \beta F_2 \quad (2)$$

Assumption 2: When focal enterprises fund and marginal enterprises do not join innovation activities, the gains of focal enterprises and marginal enterprises are as follows:

$$U_{f2} = -C_1 + T_1 + \alpha G + \beta F_1 \quad (3)$$
$$U_{m2} = K_2 I_2 - P_2 \quad (4)$$

Assumption 3: When focal enterprises do not fund and marginal enterprises join innovation activities, the gains of focal enterprises and marginal enterprises are as follows:

$$U_{f3} = K_1 I_1 - P_1 \quad (5)$$
$$U_{m3} = K_2 I_2 - C_2 + T_2 + (1-\alpha) G + \beta F_2 \quad (6)$$

Assumption 4: When focal enterprises and marginal enterprises do not cooperate, such that focal enterprises do not fund and marginal enterprises do not join innovation activities, the gains of focal enterprises and marginal enterprises are as follows:

$$U_{f4} = 0 \quad (7)$$
$$U_{m4} = K_2 I_2 \quad (8)$$

III. ANALYSIS ON MODEL PARAMETERS

A. EXPECTED BENEFITS OF PLAYERS

Assuming that the expected benefits of focal enterprises "f" choosing "fund" and "not fund" strategies are u_{f1} and u_{f2}, respectively, the $\overline{u_f}$ represents average expected utilities of focal enterprises, where:

$$\begin{aligned} u_{f1} &= y U_{f1} + (1-y) U_{f2} \\ &= y (K_1 I_1 - C_1 + R_1 + T_1 + \alpha G + \beta F_1) \\ &\quad + (1-y)(-C_1 + T_1 + \alpha G + \beta F_1) \end{aligned} \quad (9)$$
$$\begin{aligned} u_{f2} &= y U_{f3} + (1-y) U_{f4} \\ &= y (K_1 I_1 - P_1) \end{aligned} \quad (10)$$
$$\overline{u_f} = x u_{f1} + (1-x) u_{f2} \quad (11)$$

Assuming that u_{m1} and u_{m2} are the expected utilities of marginal enterprises "m" that adopt the strategies of joining and not joining, respectively. $\overline{u_m}$ indicates the average expected utilities of marginal enterprises, where

$$\begin{aligned} u_{m1} &= xU_{m1} + (1-x)\,U_{m3} \\ &= x\,[K_2I_2 - C_2 + R_2 + T_2 + (1-\alpha)\,G + \beta F_2] \\ &\quad + (1-x)\,[K_2I_2 - C_2 + T_2 + (1-\alpha)\,G + \beta F_2] \quad (12) \\ u_{m2} &= xU_{m2} + (1-x)\,U_{m4} \\ &= x\,(K_2I_2 - P_2) + (1-x)\,K_2I_2 \quad (13) \\ \overline{u_m} &= yu_{m1} + (1-y)\,u_{m2} \quad (14) \end{aligned}$$

B. THE REPLICATOR DYNAMIC EQUATION OF PLAYERS

According to the research work by Friedman [29], Xiao and Gang [30], in a replicator dynamic system, the growth rate of a strategy selected by the players should be equal to its fitness less the population average fitness among each player. Where,

The replicator dynamic equation of focal enterprises is:

$$\begin{aligned} dx/dt &= x\left(u_{f1} - \overline{u_f}\right) = x\,(1-x)\left(u_{f1} - u_{f2}\right) \\ &= x\,(1-x)\,(yK_1I_1 + yR_1 - C_1 + T_1 + \alpha G + \beta F_1) \quad (15) \end{aligned}$$

The replicator dynamic equation of marginal enterprises is

$$\begin{aligned} dy/dt &= y\,(u_{m1} - \overline{u_m}) = y\,(1-y)\,(u_{m1} - u_{m2}) \\ &= y\,(1-y)\,[xR_2 + xP_2 - C_2 + T_2 + (1-\alpha)\,G + \beta F_2] \\ &\quad (16) \end{aligned}$$

C. THE STABILITY ANALYSIS OF DYNAMIC SYSTEM

In the above dynamic system, the replicated dynamic state can be obtained, by making simultaneous replicator dynamic equation (15) and (16) equal to 0:

$$\begin{aligned} x_1^* &= 0, \\ x_2^* &= 1, \\ y^* &= \frac{C_1 - T_1 - \alpha G - \beta F_1}{K_1I_1 + R_1}. \end{aligned} \quad (17)$$

Similarly,

$$\begin{aligned} y_1^* &= 0, \\ y_2^* &= 1, \\ x^* &= \frac{C_2 - T_2 - (1-\alpha)\,G - \beta F_2}{P_2 + R_2}. \end{aligned} \quad (18)$$

Also, there are five local equilibrium points in the system, namely, $(0, 0)$, $(0, 1)$, $(1, 0)$, $(1, 1)$, and (x^*, y^*).

The stability of the dynamic system equilibrium point, described as the differential equations, can be obtained by analyzing the structure of the Jacobian matrix of the system according to Friedman's method [29]. The system's Jacobian matrix can be calculated as

$$J = \begin{pmatrix} \dfrac{\partial\,(dx/dt)}{\partial x} & \dfrac{\partial\,(dy/dt)}{\partial y} \\ \dfrac{\partial\,(dy/dt)}{\partial x} & \dfrac{\partial\,(dy/dt)}{\partial y} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}, \quad (19)$$

TABLE 2. System equilibrium point stability analysis.

	Balance point	DetJ	TrJ	Local Stability
O	$x=0, y=0$	+	-	ESS
A	$x=0, y=1$	+	+	unstable point
B	$x=1, y=0$	+	+	unstable point
C	$x=1, y=1$	+	-	ESS
D	$x=x^*, y=y^*$	-	0	saddle point

where

$$\begin{aligned} a_{11} &= (1-2x)\,(yK_1I_1 + yR_1 - C_1 + T_1 + \alpha G + \beta F_1) \quad (20) \\ a_{12} &= x\,(1-x)\,(K_1I_1 + R_1) \quad (21) \\ a_{21} &= y\,(1-y)\,(P_2 + R_2) \quad (22) \\ a_{22} &= (1-2y)\,[xP_2 + xR_2 - C_2 + T_2 + (1-\alpha)\,G + \beta F_2] \quad (23) \end{aligned}$$

If conditions are satisfied with the value of the balance point, $Det\,(J) = a_{11}a_{22} - a_{12}a_{21} > 0$, $Tr\,(J) = a_{11} + a_{22} < 0$, the equilibrium point can be considered to have local stability for the ESS at this point, as shown in Table 2.

Because of (x^*, y^*) on available area $[0, 1] \times [0, 1]$, so we can get $C_1 - T_1 - \alpha G - \beta F_1 < K_1I_1 + R_1$, which can be analyzed from the above Jacobian matrix and local stability results that five local equilibrium points for stability analysis have been obtained.

(1) If $0 < y < (C_1 - T_1 - \alpha G - \beta F_1)\,/\,(K_1I_1 + R_1)$, then there is a stable equilibrium solution for reproduction dynamic equation named $x = 0$ after taking $x = 0$ and $x = 1$ into formula (19) and concluding $a_{11} < 0$ and $a_{11} > 0$, respectively. This means that focal enterprises will tend to choose a not fund strategy.

(2) If $(C_1 - T_1 - \alpha G - \beta F_1)\,/\,(K_1I_1 + R_1) < y < 1$, then there is a stable equilibrium solution for reproduction dynamic equation named $x = 1$ after taking $x = 0$ and $x = 1$ into formula (19) and concluding $a_{11} > 0$ and $a_{11} < 0$, respectively. This means focal enterprises will tend to choose a fund strategy.

(3) If $y = (C_1 - T_1 - \alpha G - \beta F_1)\,/\,(K_1I_1 + R_1)$, which means the probability of cooperation is exactly $y = (C_1 - T_1 - \alpha G - \beta F_1)\,/\,(K_1I_1 + R_1)$, then $a_{11} = 0$ can always be established. In Figure 1, the broken line *B-D-A* shows the boundary, indicating that there is a stable equilibrium solution, whether focal enterprises select fund or not fund. The stable equilibrium is a pure strategy under the complete information, which is difficult to achieve in reality.

Similarly, we can take the perspective of marginal enterprises to get the same conclusion.

The dynamic trajectory of the system evolution is shown in Figure 1, and the final evolution result is determined by the initial state of the system and the evolutionary critical

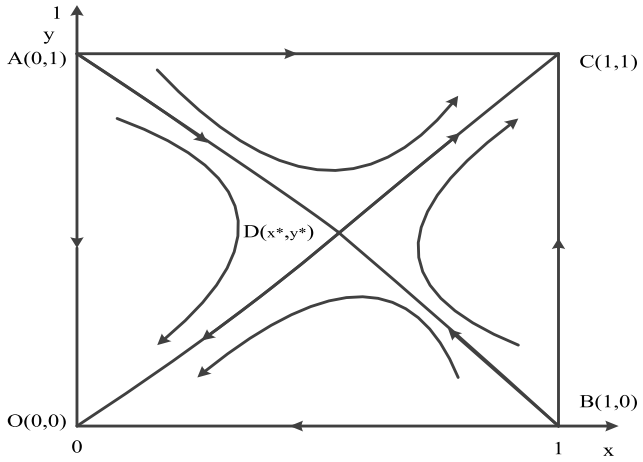

FIGURE 1. The evolutionary graph of the focal and marginal enterprises.

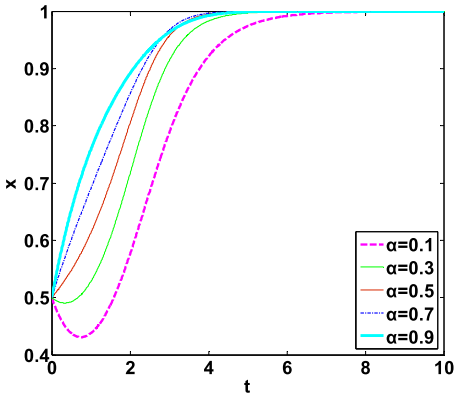

FIGURE 2. The effects of the government grant for the evolutionary strategy of focal enterprises.

TABLE 3. The simulation parameter values.

	R_1	R_2	C_1	C_2	T_1	T_2	F_1	F_2	K_1	I_1	P_2	G
1	0.5000	0.4632	0.7876	1.0000	0.1523	0.1623	0.3256	0.2385	0.7000	0.8000	0.6968	0.8889
2	0.4322	0.3512	1.0000	0.6543	0.2312	0.2103	0.1418	0.1477	0.8000	0.7800	0.4635	0.7292
3	0.3542	0.3845	0.6542	0.5745	0.1879	0.1755	0.2512	0.1536	0.7500	0.8200	0.3344	1.0000
4	1.0000	0.5546	0.7865	0.6638	0.1654	0.1533	0.4544	0.3712	0.6500	0.6600	0.5155	0.6432
5	0.7712	0.8831	0.7712	1.0000	0.3233	0.2879	0.1986	0.1032	0.6000	0.6000	0.5844	0.5342
Final	0.6115	0.5273	0.7999	0.7785	0.2120	0.1979	0.2743	0.2028	0.7000	0.7320	0.5189	0.7591

line *B-D-A*. From an intuitive point of view, the probability that the system will evolve towards absolute (Fund, Join) and absolute (Not fund, not join) strategy depends on the ratio of area *O-B-D-A* to *C-B-D-A*.

From the analysis of Table 3 and Figure 1, we can see that there are two pure strategy Nash equilibria in the game, (1,1) and (0,0). Obviously, it is consistent with the equilibrium of Stag Hunt games where bistable equilibria appear in case of symmetric 2 by 2 games [31]–[33].

IV. CASE STUDY

Although the theoretical results have been analyzed in Section III, to aid understanding, a simulation of the model is conducted to further clarify the meaning of the model. In this section, we will observe the evolution tendency of focal enterprises and marginal enterprises are affected by external factors (such as government or financial institution). There are twelve GBI manufacturing companies who have joined a R&D cooperation innovation program. According to their financial data report (*data from a Chinese R&D Cooperation Project Database*), government grant and financial support have helped them to reduce innovation cost and promote firm benefits.

A. PARAMETER SETTINGS

Above twelve GBI manufacturing companies are taken as an example. Based on Chinese *R&D Cooperation Project Database,* we get data of five different groups, each group has two enterprises (a focal enterprise, a marginal enterprise), the final parameter values through data standardization, but were modified for the confidentiality reason. In the further evaluation phase, all the data comes from the final selection stage. The simulation parameter values are shown in Table 3, which are influenced by the results in Section III. Where, the units of K_1, I_1 are(%), and the units of others are (ten thousand RMB). All of the initial strategy ratios of the two parties are 0.5; that is, $f(0) = m(0) = 0.5$, and the initial state of the strategy combination is point (0.5, 0.5). Evolutionary results can be obtained by using the final data in the model in the MATLAB platform.

B. RESULTS AND DISCUSSION

In the simulation model, five different values ($\alpha = 0.1$, 0.3, 0.5, 0.7, 0.9) of simulation experiments were conducted. We investigate the effect of the government grant and financial support for enterprises.

1) GOVERNMENT GRANT

For focal enterprises, which can be shown in Fig. 2. The lines represent the tendency of focal enterprises by selecting the different strategies. Particularly, set $\alpha = 0.1$, 0.3, 0.5, 0.7, 0.9, and the system converges fast with an increase of the government grant parameter value. When α is considerably large in actual situations, the focal enterprises will purse the fund strategy. In contrast, the convergence velocity slows down with the decrease of α, because some enterprises are

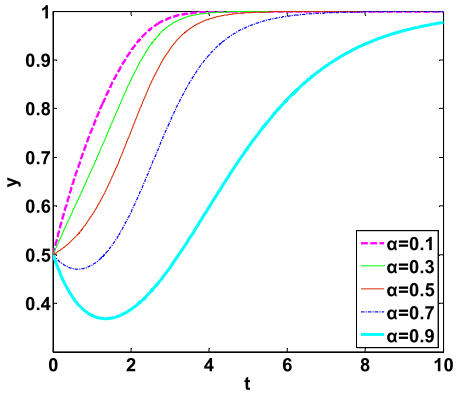

FIGURE 3. The effects of the government grant for the evolutionary strategy of marginal enterprises.

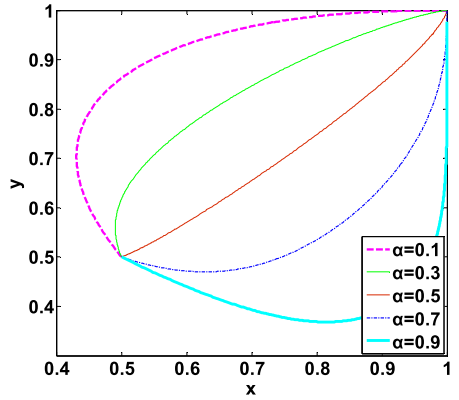

FIGURE 4. The effects of the government grant for the evolutionary strategy of all enterprises.

hesitate to their initial strategy to face their innovation costs. However, this situation, in reality, does not last for a long time, and finally all enterprises will choose fund strategy.

Similarly, we fix other parameters and change the government grant $(1-\alpha)$ for the strategy of the marginal enterprises, which range from 0.1 to 0.9. Figure 3 shows that the decrease of $(1-\alpha)$ can influence the marginal enterprises to change their strategy from not join to join, because the costs of join innovation activities increase with the reduction of government grant. When the government grant is large enough for marginal enterprises to cover their payments (we have $K_2I_2 + R_2 + T_2 + \alpha G + \beta F_2 > C_2$), which lead to the marginal enterprises choose join strategy.

We suppose "x" as the probability of the focal enterprises to fund innovation activities, "y" denotes the probability of the marginal enterprises to join the innovation activities; the initial values are (0.5, 0.5). The evolutionary paths from different government grants are shown in Figure 4. From the Figure, all enterprises converge to 1. Hence (1, 1) is the stable equilibrium point of the evolutionary game. This shows that the focal enterprises will choose to fund innovation activities, and the marginal enterprises will join these innovation activities. In the case of the government using incentives to promote innovation activities between the focal and marginal enterprises, the enterprises will not be indifferent. For the focal enterprises, if they do not fund innovation activities, the technology and knowledge may not move through the network effectively. So they will not obtain extra income. For the marginal enterprises, accepting innovation activities will acquire and provide new knowledge to the innovation network. Besides, they can get the subsidies of the government and gain the incentives of tax. Therefore, they will not refuse these cooperation opportunities.

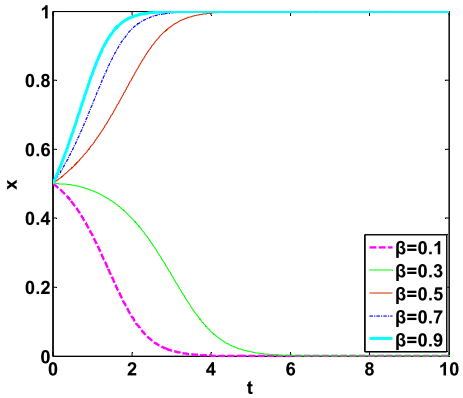

FIGURE 5. The effects of the financial support for the evolutionary strategy of focal enterprises.

It is easy to understand that the rational enterprises have to be silent when innovation cost is too high. If the cost is somewhat bearable (or irrationally considered as bearable), the focal enterprises can easily promote trust between players, and other enterprises throughout the network will rapidly imitate their innovation, the marginal enterprises would provide new knowledge to the innovation network. Ultimately, all focal enterprises choose the fund strategy, all marginal enterprises choose the join strategy, thus reaching the equilibrium point (1, 1). The strategy set of the system is (fund, join).

2) FINANCIAL SUPPORT

In order to test the impact of financial support parameter value to the focal enterprises, the parameter β, which is set to range from 0.1 to 0.9, while fixing other parameters. The simulation results are calculated and shown in Figure 5. Simulation results indicate that the strategy of focal enterprises gradually changes from not fund to fund with an increase of financial support parameters. Some enterprises will adopt the fund strategy in actual situations, such as decreasing the cost of innovation activities, or enhancing financial support from the financial institution $(T_1 + \alpha G + \beta F_1 + K_1I_1 + R_1 > C_1)$.

Similarly, we can take the perspective of marginal enterprises to get the same conclusion. The simulation results are calculated and shown in Figure 6.

The initial values are (0.5, 0.5), and the evolutionary paths from different financial supports are shown in Figure 7. From the Figure, all enterprises finally converge to 1. Hence, (1, 1) is the stable equilibrium point. This shows focal enterprises

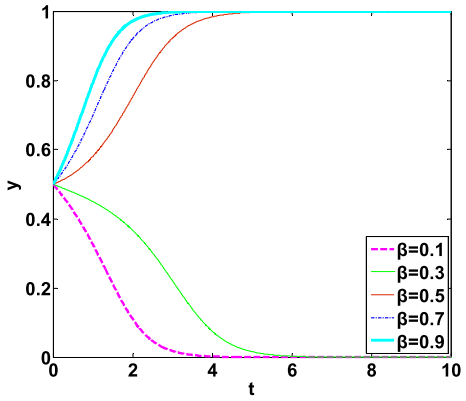

FIGURE 6. The effects of the financial support for the evolutionary strategy of marginal enterprises.

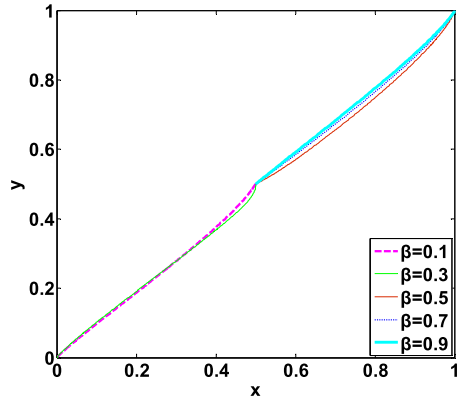

FIGURE 7. The effects of the financial support for the evolutionary strategy of all enterprises.

will choose the fund strategy, and the marginal enterprises will choose the join strategy. According to the above analysis, by existing GBI innovation network, on one hand, the focal enterprises have strong ties in innovation network, and they can easily promote any type of information, especially knowledge and technological information, flow by means of their direct relationships. At the same time, the focal enterprises can acquire new knowledge from the innovation network. On the one hand, the marginal enterprises have weak ties within the network but still have the possibility to provide heterogeneous (different) knowledge to the innovation network, and acquire extra benefits. Therefore, all enterprises will choose the cooperate strategy. Although the focal enterprises and marginal enterprises can reduce the innovation cost by cooperation, but when the β is chosen as $\beta = 0.1, 0.3$, all enterprises will choose silence, they will converge to 0. When $\beta = 0.5, 0.7, 0.9$, the gains of all enterprises are bigger, then they will quickly converge to 1.

The benefits of enterprises are very large as enterprises' cooperative innovation and the grant of government. In addition to these, the enterprises would obtain more benefits through the financial support. With more financial support, which would make the enterprises quickly converge to 1, e.g., green credit, green bonds, green insurance and green fund for the GBI [34].

V. CONCLUSIONS

A. THEORETICAL IMPLICATIONS

The GBI plays an important role in promoting the development of environmental management and economic development. As a still-emerging industry, which has great potential for development. In this study, based on innovation networks, the evolutionary game method is used to establish the cooperative innovation mechanism model among enterprises. The converge of enterprises' innovation strategies is also analyzed under different equilibrium situations. Finally, it is found that government grant and financial support are critical for promoting the development of the GBI, which further enriches research on the innovation strategies. Thus, the following conclusions are drawn.

(1) Focal enterprises have strong significant ties to many structural holes in an innovation network. They easily promote any kind of information, especially knowledge and technology, flow through their relationships. The strong relationships between the nodes eliminate the problem of their wavering confidence in each other. If the focal enterprises fund an innovative activity, it easily promotes trust between players and other enterprises throughout the network, which lead to rapid imitations of their innovation. Even though the marginal enterprises have weak ties, they still generate new ideas and information easily. They have the ability to acquire and provide new technology and knowledge to the innovation network.

(2) Once the converge of the innovation strategy is completed, they spread faster because the enterprises' strategies contended and converted under different equilibrium situations. The game then gradually converge to the equilibrium point (0,0) or (1,1). The enterprises then measure the cooperative innovation costs and make the best decision.

(3) In the evolutionary process of the game, government grant and financial support are critical in promoting the development of the GBI. When governmental and financial institutions give all enterprises appropriate support, the evolutionary game reach the desired equilibrium point (1,1). The converge speed of innovation strategies is faster with higher governmental subsidies and financial support.

B. PRACTICAL IMPLICATIONS

What we find is interesting and valuable for GBI policy. What should we do about the promotion of GBI? We need to take four steps:

(1) To improve the government's supervision system, government procurement should be classified. The government should give the priority to the GBI products. For some enterprises who failed to produce green

products and couldn't meet the requirements of environment protection, the government can give their chance to adjust their strategy.

(2) Establishing an effective punishment mechanism, and introducing a "credit point system" to carry out high rewards and punish the enterprises that satisfy and fail to satisfy emission standards. Then, promoting the improvement of GBI emission technology. In addition, the government should introduce more laws on environment regulation, and increase the environment violation costs. Then, also, the government should enforce the strength of environment law. By all the way, the more enterprises will choose to transform, the more GBP will be produced.

(3) Continue to play the leading role of the government in promoting the research and development of GB technologies. Formulating scientific and technological support policies conducive to the development of GBI, and establishing an alliance of industry, university and research institution. Then, we need to strengthen the system and operation mechanism of the industry-university-research alliance. To promote the large-scale small and medium-sized enterprises, universities, research institutes to form a collaborative platform for R&D, and focus on the development of common materials and basic technologies such as key materials and building systems. Finally, increasing the government's financial investment in the field of GB' R&D, especially, for core technologies and key components. Financial support should maximize the role of market allocation resources to enhance the independent innovation capability of enterprises.

(4) Pay attention to the construction and improvement of infrastructure. Establishing a reasonable investment return mechanism, encourage social capital to enter the service areas of GBI facilities construction and operation, areas leasing, material recycling and other services, and reduce the entry threshold of relevant investors, so as to explore a reasonable and effective business model in line with the development of GBI.

C. LIMITATIONS AND FUTURE RESEARCH

This study has a number of limitations. The method of this study uses the three players game, maybe four players or more players will have different result. In this article, we use social network characteristics at the core and edge level, but we cannot completely put our model in a network environment. In future, we can provide a multilevel network, and respectively, to build a game theory model. The dynamic mechanism involved in the GBI innovation activities should be extensively explored in our future study.

VI. SYMBOL AND DEFINITION

I_1, I_2: Innovation level of focal and marginal enterprises, respectively, and I_1 and $I_2 > 0$.

K_1, K_2: Absorptive and transformative capacity of the new knowledge and technology (innovation income coefficient).

C_1, C_2: Cooperation and innovation costs of focal and marginal enterprises.

R_1, R_2: Additional income of focal and marginal enterprises.

T_1, T_2: Tax incentive of the enterprise.

P_1, P_2: These are punishment values that the result of focal enterprises is not funding innovation activities when the marginal enterprises are joining activities positive. Or the situation occurs when the focal enterprises' funding mechanism is active, marginal enterprises are not joining innovation activities.

G: Government grant for the focal enterprise (α G) and marginal enterprise ($(1-\alpha)$G). α is a distribution coefficient, $\alpha \in [0, 1]$.

F_1, F_2: Financial support for the innovation activities. β is a supporting coefficient, $\beta \in [0, 1]$.

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