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How Does the Government Promote the Collaborative Innovation of Green Building Projects? An Evolutionary Game Perspective

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Abstract: In order to study how to promote the collaborative innovation of green building projects of construction enterprises, this paper establishes an evolutionary game model of suppliers' participation in collaborative innovation of green building projects of construction enterprises under government governance. Through a numerical simulation, our research analyzes the influence of government tax preference, government infrastructure construction, and environmental pollution punishment on the behavior of the government, suppliers, and construction enterprises. The empirical research shows that the government's tax incentives will continue to encourage suppliers to choose collaborative innovation. If the government's short-term tax incentives are small, construction enterprises will evolve in the direction of midway betrayal. When the government's long-term tax incentives are large, construction enterprises will evolve in the direction of the collaborative innovation of green building projects. Furthermore, the government's infrastructure support for suppliers to participate in collaborative innovation of green building projects of construction enterprises will encourage suppliers and construction enterprises to choose green building projects for collaborative innovation. With the continuous maturity of green building projects in the construction market, the government has evolved from positive governance to negative governance. The government will take the opportunity to give up infrastructure construction and turn to other supporting policies. Lastly, a low intensity of environmental pollution punishment makes it difficult to promote the construction enterprises to evolve in the direction of collaborative innovation. A moderate intensity of environmental pollution punishment can encourage construction enterprises to evolve in the direction of collaborative innovation, while high-intensity environmental pollution punishment can encourage construction enterprises to choose the direction of midway betrayal. Environmental pollution punishment has no significant impact on suppliers' selection of collaborative innovation of green building projects in the short term.

Keywords: green building projects; construction enterprises; collaborative innovation; evolutionary game

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1. Introduction

As one of the pillar industries of China's economic development, the construction industry plays a very important role in promoting the rapid development of China's economy and society and the people's quality of life. However, the rapid expansion of China's construction industry has led to a large amount of energy consumption, as well as a large amount of construction waste and carbon emissions; accordingly, the green innovation of construction enterprises has attracted widespread attention to achieve sustainable development and reduce environmental pollution as much as possible [1,2]. In this way, the environmental pollution of buildings has been reduced as much as possible. Green innovation can not only reduce the impact of production activities on the environment, but also play a key role in creating a more sustainable economic and social value. Therefore, it is urgent to actively carry out green innovation activities of construction enterprises and develop corresponding green new products, so as to realize the rational use of resources, as well as sustainable development and growth, effectively improve the ecological environment, promote sustainable development of enterprises, and enhance the competitive advantage of green innovation [3,4].

Because the development of green technology innovation of Chinese construction enterprises is restricted by many factors, most Chinese construction enterprises choose to give up green technology innovation. As a result, the development of green technology innovation in China lags behind that of developed countries [5]. To reverse this situation, construction enterprises gradually carry out green innovation through collaborative cooperation. In the construction product innovation activities, the green building project innovation of construction enterprises is a complex innovation behavior, involving many subjects, including the government, other enterprises, and universities. It is necessary to cooperate with each other [5–7]. Construction enterprises are the main body of innovation, while the government is the corresponding promoter. With the support of government policies, construction enterprises cooperate closely with suppliers. The willingness of cooperation between construction enterprises and suppliers is increasing [8], whereby supplier participation in green project innovation of construction enterprises enables construction enterprises to solve the problem of insufficient knowledge, technology, and other related resources in the innovation process by consulting with suppliers to design products and jointly determine green raw material standards and design specifications, so as to carry out the collaborative innovation of green building projects among enterprises [9]. The participation of suppliers in green project innovation of construction enterprises can not only effectively reduce the innovation risk and cost but also accelerate the industrialization process of construction products [10]. Suppliers' participation in green project collaborative innovation has been widely recognized by construction enterprises. However, there are still many problems in the collaborative innovation system, such as a lack of collaborative innovation motivation, imperfect collaborative innovation infrastructure, and opportunistic behavior of suppliers (leakage of core knowledge, violation of resource allocation commitment, and violation of collaborative innovation norms).

The role of the government in the market is as a regulator, participant, and policy-maker. The role of the government in the collaborative innovation system of green building projects of construction enterprises is to promote innovation or formulate government regulations [11]. It is necessary to formulate strict environmental laws and regulations to encourage innovation, support and encourage enterprises to invest in pollution-free technologies, upgrade corresponding equipment, and improve technologies [12,13], so as to stimulate enterprises to better carry out collaborative innovation of green building projects. As the top-level design and coordination elements, how to create a good policy environment, how to promote collaborative innovation of green building projects of construction enterprises, and how to enhance the enthusiasm of suppliers to participate in collaborative innovation of green building projects of construction enterprises have become urgent problems to be solved. This study analyzes the evolution process of the collaborative innovation of green building projects with respect to the equilibrium strategy of construction enterprises in different scenarios, as well as determines the government behavior factors and strategy selections that affect this system equilibrium.

The structure of this paper is as follows: Section 2 reviews the previous research and identifies the existing research gaps. Section 3 introduces the evolutionary game model of green building project collaborative innovation of construction enterprises, including its basic assumptions, model construction, and dynamic replication equation. Section 4 uses MATLAB to apply a numerical simulation to the construction enterprise green project coordinated green innovation game. Section 5 draws the corresponding conclusions and discusses the analysis through the evolutionary game simulation.

2. Literature Review

In the construction supply chain, the supply chain of integrated green building materials has become an important element for collaborative green innovation of construction enterprises [14]. It has been found that the partner choice of green technology innovation is an important factor affecting the green innovation among enterprises in the supply chain of integrated green building materials. Both internal and external green orientation of construction enterprises will promote green cooperation and innovation between enterprises and suppliers, as well as between enterprises and customers [15]. Suppliers participate in the collaborative innovation activities of green building projects, and enterprises fully acquire and utilize the professional knowledge and technology of suppliers. It is an enterprise that integrates external suppliers' knowledge, while expanding and updating its own knowledge base [16,17]. Colin, applying resource-based theory, knowledge-based theory, and capability theory, discussed the diversified sustainable development orientation of green entrants and the key factors affecting green innovation performance [9]. Other studies discussed the role of suppliers in successfully implementing green innovation capability in enterprise product development [18,19].

Olanipekun et al. believed that incentive policy is the key means to promote the development of green building market [20]. From the perspective of green building developers and consumers, Rehn and Ade introduced government subsidies, analyzed the dynamic evolution path of developers and consumers, and proposed incentive policies [21]. Zhao et al. established the corresponding evolutionary game model by studying the subsidies to enterprises in the green supply chain and giving appropriate subsidies to consumers when making green production decisions [22]. The study found that not only does direct financial support have an impact on the green technology innovation of small and medium-sized enterprises, but the construction of the regional environment is also very important for small and medium-sized enterprises [23]. Chang et al. pointed out that the government's incentive policies can promote the application of renewable energy in construction and infrastructure construction [24]. Environmental regulation has a positive impact on the green technology innovation of construction enterprises [25].

Considering a management system composed of the government and two competing enterprises which are producing green products, a game model was constructed to seek the optimal subsidy amount of the government [26]. The subsidies had a positive effect on green product innovation, whereas voluntary agreement had no effect on green product innovation, and tax laws and regulations on green product innovation produced a negative influence. This was mainly due to reduced financial input resources available for product innovation [27]. Daddi et al. (2010) proved through empirical analysis that the impact of environmental regulation on enterprise technological innovation is constantly changing with the adjustment of time and external factors, and there is no definite positive or negative impact in the long term [28]. As the external environment manager of the country, the government will be passively affected by the collaborative innovation behavior of enterprises, becoming a stakeholder of green collaborative innovation, and its environmental regulation means will indirectly affect the green innovation behavior of enterprises [29]. Cohen et al. (2017) believed that the government should provide incentive policies for builders and buyers, which would not bring too much cost to government departments [30]. Government grants and financial support are considered key to promoting the development of green building products, and government regulation, government procurement, and research and development are important components of the green building industry [31]. Green building infrastructure construction projects are an important governance mechanism for the rapid development of the green building material industry, and green innovation subsidies are a core governance mechanism for high-quality development. Pollution punishment and fraud compensation punishment for green building materials enterprises, green innovation subsidies for green building developers tax incentives, and purchase subsidies for consumers are conducive to the transformation of green production and consumption concepts.

Infrastructure construction is conducive to promoting building through the development and purchase of green building materials [32].

Enterprises in the construction supply chain strive to adopt advanced science and technology to promote collaborative innovation. The collaborative innovation cooperation of green building projects promotes the research and development of new products, new technologies, new methods, etc. In the collaborative innovation process, the construction supply chain partners provide corresponding technology and resource support [1]. Enterprises can improve efficiency in the new knowledge developed by collaborative innovation activities, as well as launch innovative products faster with less research and development costs. Participating in collaborative innovation activities is one of the important behaviors [33] under the situation of open innovation, whereby more and more construction enterprises are crossing industrial fields, breaking regional restrictions, and building collaborative innovation networks that conform to their own development and system. Construction enterprises are project-driven enterprises, and all kinds of business activities of enterprises are carried out around engineering projects. There is coordination and interaction between construction enterprises and their stakeholders at every moment in the process from the initiation of engineering projects to the delivery to the construction party. The innovation of small project-based companies is usually closely related to their business activities and is driven by owners who use very scarce resources to make progress in normal business gaps [34]. Technological progress is the main means to drive the innovation of construction projects [35]. The motivation for a single enterprise to adopt innovation in construction projects is driven by the exchange and interaction between the relevant subjects involved in innovation [36]. By interacting with other enterprises in the supply chain of the construction industry, enterprises can find new opportunities and acquire new knowledge, which is also necessary knowledge to solve important problems and difficulties in construction projects [37]. By participating in collaborative innovation activities, knowledge integration and reorganization can be achieved through mutual exchange, and mutual cooperation can further increase collaborative innovation among participants in green building projects as an effective way to break through the obstacles of building development. It is difficult for a single enterprise to innovate independently and complete the project tasks. It is necessary to form a construction industry alliance with other enterprises.

This paper has several theoretical and practical contributions. Firstly, because the research on government behavior is still in the theoretical stage, not well combined with practice, and since there is less research on the dynamic change of government policy in government behavior, this paper further enriches the research on government regulation behavior and explores the dynamic change mechanism of government policy in government behavior. Second, although some scholars have studied the evolutionary behavior of green technology innovation of construction enterprises, there is no research on the evolutionary behavior of suppliers taking part in green project collaborative innovation of construction enterprises based on government behavior. This paper extends the micro-research on the impact of government behavior on suppliers' participation in collaborative innovation of green building projects of construction enterprises. Third, the evolutionary game theory can clearly describe the decision-making process and learning behavior of participants in the green project collaborative innovation of construction enterprises, reveal their dynamic evolution process, and analyze and predict the group behavior of the participants from the perspective of bounded rationality. Therefore, this paper uses evolutionary game theory to describe the decision-making process of green building project collaborative innovation by the government, supplier, and construction enterprise.

3. The Model

3.1. Analysis of the Interests of the Three Parties

Green project innovation cooperation among construction enterprises is mainly based on the actual needs of engineering cooperation projects [38]. In the collaborative innovation of green building projects of construction enterprises, construction enterprises and suppliers maintain active and effective communication. Both parties communicate product design information and product plans through corresponding channels, to realize product innovation. Through their own market capacity, suppliers will gradually guide enterprises to change toward the direction of green project innovation. Construction enterprises carry out green project innovation, produce an innovation effect, and gradually expand. The government attaches great importance to the collaborative innovation of green building projects of suppliers and construction enterprises. The government gives corresponding subsidies or preferential treatment to suppliers and construction enterprises' green project innovation, so as to gradually promote the diffusion of green innovative products. The government integrates environmental protection into the development of suppliers and construction enterprises. Because of the environmental pollution, the government has taken measures to punish the environmental pollution, gradually hindering the circulation of traditional nonenvironmental protection products on the market. Suppliers and construction enterprises have to change their product development means and carry out collaborative innovation of green projects. The government's governance can guide suppliers and construction enterprises to regulate their own behavior and obtain corresponding benefits.

3.2. Construction of Evolutionary Game Model for Collaborative Innovation of Green Building Projects in Construction Enterprises

Assumption 1. *In the natural environment, without considering other constraints, while considering the overall system of the government, construction enterprises, and suppliers from the perspective of suppliers' participation in collaborative innovation of green building projects of construction enterprises, the participants are bounded rationally. In the process of collaborative innovation of green building projects, the participants have limited information, thus exhibiting incomplete symmetry [39–41].*

Assumption 2. *It is difficult to realize the collaborative innovation of green building projects solely relying on the market economy system, and the government needs to correct the market mechanism. The government's infrastructure construction can effectively offset the shortage of funds in the collaborative innovation of green building projects and build a green innovation platform. The government stimulates the development and production of green products of construction enterprises by improving the tax preferential policy system. When construction enterprises introduce new green technologies, it is conducive to the promotion and application of green technology innovation. However, if construction enterprises withdraw from the collaborative innovation of green building projects and fail to adopt green technologies, corresponding environmental pollution problems will emerge, and corresponding punishments will be applied. In order to better explore the role of the government, the government's role in the collaborative innovation of green building projects of construction enterprises is divided into tax incentives, government infrastructure construction, and environmental pollution punishment α, β, γ. The cost of government consumption is denoted by $\alpha S, \beta I, \gamma P$. The collaborative innovation of green building projects of construction enterprises as a function of government governance can lead to innovation. The government's tax preferences for collaborative innovation of suppliers and construction enterprises are $\alpha S_1, \alpha S_2$, respectively. When the supplier and the construction enterprise are betrayed in the middle of the project, they are punished by the government for environmental pollution ($\gamma P_1, \gamma P_2$).*

Assumption 3. *When suppliers participate in collaborative innovation of green building projects of construction enterprises, suppliers and construction enterprises are in a game for the collaborative innovation of green projects. When both suppliers and construction enterprises choose to quit halfway, the corresponding costs of suppliers and construction enterprises are C_{g1} and C_{z1}, respectively. The profits obtained by both parties are R_g and R_z. When suppliers and construction enterprises carry out collaborative innovation of green building projects according to certain rules, corresponding green technologies are adopted for green project development, while corresponding R&D and new equipment are introduced. The corresponding costs of suppliers and construction enterprises are C_{g2} and C_{z2}. The profit is higher than the original ΔR_1 and ΔR_2. The government's revenue is R. The corresponding loss is L. In the collaborative innovation of green building projects between* *suppliers and construction enterprises, when the government takes the initiative to govern, the government supervises the collaborative innovation of green building projects between suppliers and construction enterprises to avoid the occurrence of intellectual property disputes and opportunism. At this time, the profits of suppliers increase ($\mu\Delta R_1'$). The income of construction enterprises also increases ($(1-\mu)\Delta R_1'$). When the government carries out passive governance, the government formulates corresponding policies to encourage the supplier and the construction enterprise to establish a good cooperative relationship, and the supplier's income decreases ($\mu\Delta R_2'$), while the profits of construction enterprises decrease ($(1-\mu)\Delta R_2'$).*

Assumption 4. *Due to the supplier dependence, there is mutual dependence between the supplier and the construction enterprise. However, once only one party carries out the green project collaborative innovation, the supplier and the construction enterprise will choose the strategy of midway betrayal for some reasons. Both sides agree that, when one party betrays halfway and chooses to quit, the other party's income from the other party is D. To achieve the goal of collaborative innovation in the green building project, if one party betrays the green building project, whereby the betrayer gives up the green building project and turns to the nongreen building project, this is punishable due to the corresponding environmental pollution.*

Assumption 5. *The participants in the game model include suppliers, construction enterprises, and the government. Each participant has two behavior choices, i.e., construction enterprises and suppliers choose collaborative innovation or midway betrayal, and the government chooses active or negative governance. Here, x, y, z represent the selection probabilities of the corresponding strategies, and $x, y, z \in [0,1]$ is a function of time. In the process of learning and imitation, the three sides of the game adjust their own strategies through trial and error or choice, in order to find a better strategy, until a balance is reached.*

3.3. The Dynamic Replication Equation of Evolutionary Game Subjects

According to the above assumptions, the evolutionary game income payment matrix of suppliers (x), construction enterprises (y), and governments (z) is constructed in Tables 1–5.

Table 1. The tripartite game payment matrix of suppliers' participation in collaborative innovation of green building projects of construction enterprises (x).

	Active Governance by Government (z)		
	Supplier Payments	**Construction Enterprises Payments**	**Government Payments**
Collaborative innovation of construction enterprises (y)	$R_g + \Delta R_1 + \mu\Delta R_1' + \alpha S_1 - C_{g2}$	$R_z + \Delta R_2 + (1-\mu)\Delta R_1' + \alpha S_2 - C_{z2}$	$R - \alpha(S_1 + S_2) - \beta I$
Betrayal of construction enterprises ($1-y$)	$R_g + \Delta R_1 + \alpha S_1 - C_{g2} - D$	$R_Z - \gamma P_2 - C_{Z2} + D$	$\gamma P_2 - \alpha S_1 - L$

Table 2. The tripartite game payment matrix of suppliers' participation in collaborative innovation of green building projects of construction enterprises (x).

	Passive Governance by Government ($1-z$)		
	Supplier Payments	**Construction Enterprises Payments**	**Government Payments**
Collaborative innovation of construction enterprises (y)	$R_g + \Delta R_1 - C_{g2}$	$R_z + \Delta R_2 - C_{z2}$	R
Betrayal of construction enterprises ($1-y$)	$R_g + \Delta R_1 - C_{g2} - D$	$R_Z - \gamma P_2 - C_{Z2} + D$	$\gamma P_2 - L$

Table 3. The tripartite game payment matrix of supplier betrayal $(1-x)$.

	Active Governance by Government (z)		
	Supplier Payments	**Construction Enterprises Payments**	**Government Payments**
Collaborative innovation of construction enterprises (y)	$R_g - C_{g2} - \gamma P_1 - \alpha S_1 + D$	$R_z + \Delta R_2 + \alpha S_2 - C_{z2} - D$	$R - \alpha S_2 + \alpha S_1 + \gamma P_1$
Betrayal of construction enterprises $(1-y)$	$R_g - C_{g2} - \gamma P_1 - \alpha S_1$	$R_Z - C_{Z2} - \gamma P_2 - \alpha S_2$	$\gamma(P_1 + P_2) + \alpha(S_1 + S_2) - L$

Table 4. The tripartite game payment matrix of supplier betrayal $(1-x)$.

	Passive Governance by Government (1 – z)		
	Supplier Payments	**Construction Enterprises Payments**	**Government Payments**
Collaborative innovation of construction enterprises (y)	$R_g - C_{g2} - \gamma P_1 + D$	$R_z + \Delta R_2 - C_{z2} - D$	$R + \gamma P_1$
Betrayal of construction enterprises $1-y$	$R_g - C_{g2} - \gamma P_1 - \mu\Delta R'_2$	$R_Z - C_{Z2} - \gamma P_2 - (1-\mu)\Delta R'_2$	$\gamma(P_1 + P_2) - L$

Table 5. Jacobian matrix.

Equilibrium Point	Characteristic Value	Characteristic Value	Characteristic Value
$J_1(0,0,0)$	$\Delta R_1 - D + \gamma P_1 + \mu\Delta R'_2$	$\Delta R_2 - D + \gamma P_2 + (1-\mu)\Delta R'_2$	0
$J_1(0,0,1)$	$2\alpha S_1 + \Delta R_1 - D + \gamma P_1 + \mu\Delta R'_2 - \mu\Delta R'_2$	$(1-\mu)\Delta R'_1 + \Delta R_z - D + \gamma P_2$	0
$J_1(0,1,0)$	$\Delta R_1 - D + \gamma P_1 + \mu\Delta R'_2 - \mu\Delta R'_2$	$-[(1-\mu)\Delta R'_1 + \Delta R_z - D + \gamma P_2 + (1-\mu)\Delta R'_2]$	$R - \alpha S_2$
$J_1(1,0,0)$	$-(\Delta R_1 - D + \gamma P_1 + \mu\Delta R'_2)$	$[(1-\mu)\Delta R'_1 + \Delta R_z - D + \gamma P_2 + (1-\mu)(1-x)\Delta R'_2]$	$-\alpha S_1$
$J_1(0,1,1)$	$\mu\Delta R'_1 + 2\alpha S_1 + C_{g2} + \Delta R_1 - D + \gamma P_1$	$-[(1-\mu)\Delta R'_1 + \Delta R_z - D + \gamma P_2]$	$-(R - \alpha S_2)$
$J_1(1,0,1)$	$-(2\alpha S_1 + \Delta R_1 - D + \gamma P_1)$	$(1-\mu)\Delta R'_1 + \Delta R_z - D - \alpha S_2 + \gamma P_2$	αS_1
$J_1(1,1,0)$	$-(\Delta R_1 - D + \gamma P_1)$	$-[(1-\mu)\Delta R'_1 + \Delta R_z - D + \gamma P_2]$	$-\beta I + R - \alpha S_2$
$J_1(1,1,1)$	$-(\mu\Delta R'_1 + 2\alpha S_1 + C_{g2} + \Delta R_1 - D + \gamma P_1)$	$-[(1-\mu)\Delta R'_1 + \Delta R_z - D - \alpha S_2 + \gamma P_2]$	$\beta I - R + \alpha S_2$

Expected average revenue of suppliers:

$$E_1 = E_{11}x + E_{12}(1-x) \quad (1)$$

The benefits of collaborative innovation of green building projects selected by suppliers:

$$E_{11} = yz(R_g + \Delta R_1 + \mu\Delta R'_1 + \alpha S_1 - C_{g2}) + z(1-y)(R_g + \Delta R_1 + \alpha S_1 - C_{g2} - D) + y(1-z)(R_g + \Delta R_1 - C_{g2}) + (1-z)(1-y)(R_g + \Delta R_1 - C_{g2} - D) \quad (2)$$

The benefits when suppliers choose green building projects to betray halfway:

$$E_{12} = zy(R_g - C_{g2} - \gamma P_1 - \alpha S_1 + D) + z(1-y)(R_g - C_{g2} - \gamma P_1 - \alpha S_1) + y(1-z)(R_g - C_{g2} - \gamma P_1 + D) + (1-y)(1-z)(R_g - C_{g2} - \gamma P_1 - \mu\Delta R'_2) \quad (3)$$

The supplier's dynamic replication equation:

$$U(x) = x(1-x)(yz\mu\Delta R'_1 + 2\alpha z S_1 + yzC_{g2} + \Delta R_1 - D + \gamma P_1 + \mu\Delta R'_2 - z\mu\Delta R'_2 - y\mu\Delta R'_2 + zy\mu\Delta R'_2) \quad (4)$$

Expected average income of construction enterprises:

$$E_2 = E_{21}y + E_{22}(1-y) \quad (5)$$

The benefits of collaborative innovation of green building projects selected by construction enterprises:

$$E_{21} = xz[R_z + \Delta R_2 + (1-\mu)\Delta R_1' + \alpha S_2 - C_{z2}] + x(1-z)(R_z + \Delta R_2 - C_{z2}) + z(1-x)(R_z + \Delta R_2 + \alpha S_2 - C_{z2} - D) + (1-x)(1-z)(R_z + \Delta R_2 - C_{z2} - D) \quad (6)$$

The benefits when construction enterprises choose to betray green building projects halfway:

$$E_{22} = xz(R_Z - \gamma P_2 - C_{Z2} + D) + x(1-z)(R_Z - \gamma P_2 - C_{Z2} + D) + z(1-x)(R_Z - C_{Z2} - \gamma P_2 - \alpha S_2) + (1-x)(1-z)[R_Z - C_{Z2} - \gamma P_2 - (1-\mu)\Delta R_2'] \quad (7)$$

The construction enterprise's dynamic replication equation:

$$U(y) = y(1-y)[(1-\mu)\Delta R_1' + \Delta R_z - D - \alpha xzS_2 + \gamma P_2 + (1-\mu)(1-x-z+xz)\Delta R_2'] \quad (8)$$

Expected average revenue of government:

$$E_3 = E_{31}z + E_{32}(1-z) \quad (9)$$

The benefits of government's active governance strategy:

$$E31 = xy[R - \alpha(S_1 + S_2) - \beta I] + x(1-y)(\gamma P_2 - \alpha S_1 - L) + (1-x)y(R - \alpha S_2 + \gamma P_1) + (1-x)(1-y)[\gamma(P_1 + P_2) - L] \quad (10)$$

The benefits of government's passive governance strategy:

$$E32 = xyR + x(1-y)(\gamma P_2 - L) + (1-x)y(R + \gamma P_1) + (1-x)(1-y)[\gamma(P_1 + P_2) - L] \quad (11)$$

The government's dynamic replication equation:

$$U(Z) = z(1-z)(\alpha xyS_1 - \beta Ixy - \alpha xS_1 + yR - \alpha yS_2) \quad (12)$$

3.4. Stability Analysis of the Three Parties Involved in the Game

Equilibrium refers to the realization of the maximum utility of each party in the game, i.e., the realization of each party's satisfaction with the game result, such that the actual utility and satisfaction degree of each party are different. In the evolution of a stable strategy, both sides adopt an optimal response strategy. Thus, an evolutionary game model of suppliers, construction enterprises, and the government can be established to analyze the stability of the three parties, with the following equilibrium points:

$$\begin{cases} U_1'(x) = 0 \\ U_2'(y) = 0 \\ U_3'(z) = 0 \end{cases} \quad (13)$$

According to Equation (13), in terms of income, $\{(x, y, z) \mid 0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq z \leq 1\}$, eight equilibrium points are obtained through calculation and analysis.

In order to simplify the formula, let

$$\begin{cases} T_1(y,z) = yz\mu\Delta R_1' + 2\alpha zS_1 + yzC_{g2} + \Delta R_1 - D + \gamma P_1 + \mu\Delta R_2' - z\mu\Delta R_2' - y\mu\Delta R_2' + zy\mu\Delta R_2' \\ T_2(x,z) = (1-\mu)\Delta R_1' + \Delta R_z - D - \alpha xzS_2 + \gamma P_2 + (1-\mu)(1-x-z+xz)\Delta R_2' \\ T_3(x,y) = \alpha xyS_1 - \beta Ixy - \alpha xS_1 + yR - \alpha yS_2 \end{cases} \quad (14)$$

In the above equilibrium point, the following equation is satisfied:

$$\begin{cases} T_1(y,z) = 0 \\ T_2(x,z) = 0 \\ T_3(x,y) = 0 \end{cases} \quad (15)$$

According to the evolutionary game theory, when $U_1'(x) < 0$, $U_2'(y) < 0$, and $U_3'(z) < 0$, Equation (13) is the stable strategy (ESS) of the tripartite game among suppliers, construction enterprises, and the government.

$$\begin{cases} U_1'(x) = (1-2x)T_1(y,z) \\ U_2'(y) = (1-2y)T_2(x,z) \\ U_3'(z) = (1-2z)T_3(x,y) \end{cases} \quad (16)$$

For suppliers, when $T_1(y,z) > 0$, $U_1'(0) > 0$, and $U_1'(1) < 0$, the supplier chooses the green building project collaborative innovation as a stable state. On the contrary, midway betrayal is a stable state. Because $x \in (0,1)$, $U_1'(x) > 0$, the evolutionary phase diagram of a supplier choosing to participate in green building project collaborative innovation depends on the curve shape of Equation (16).

For construction enterprises, if $T_2(x,z) > 0$, then $U_2'(0) > 0$, $U_2'(1) < 0$, indicating that construction enterprises choose green building project collaborative innovation as a stable state. On the contrary, construction enterprises choose to betray as a stable state. Because $x \in (0,1)$, $U_2'(y) > 0$, the evolution phase diagram of the stability of collaborative innovation of green building projects selected by construction enterprises depends on the curve form of Equation (16).

For the government, the dividing line determining a stable state is $T_3(x,y) = 0$. If $T_3(x,y) > 0$, then $U_3'(0) > 0$, and $U_3'(1) < 0$, revealing that the stable state of the government evolutionary game actively governs the suppliers' participation in the collaborative innovation development of green building projects of construction enterprises. On the contrary, the government's passive governance is a stable state. The evolution phase diagram of government stability depends on the curve form of Equation (16).

According to Lyapunov stability theory, the asymptotic stability of the system at the equilibrium point can be judged by analyzing the eigenvalues of the system Jacobian matrix. The Jacobian matrix of the system is obtained as follows:

$$J = \begin{vmatrix} \frac{du(x)}{dx} & \frac{du(x)}{dy} & \frac{du(x)}{dz} \\ \frac{du(y)}{dx} & \frac{du(y)}{dy} & \frac{du(y)}{dz} \\ \frac{du(z)}{dx} & \frac{du(z)}{dy} & \frac{du(z)}{dz} \end{vmatrix}$$

$$= \begin{vmatrix} U_1'(x) & x(1-x)(z\mu\Delta R_1' + zC_{g2} - \mu\Delta R_2' + y\mu\Delta R_2') & x(1-x)(y\mu\Delta R_1' + 2\alpha S_1 + yC_{g2} - \mu\Delta R_2' + y\mu\Delta R_2') \\ y(1-y)[-\alpha z S_2 + (1-\mu)(-1+x)\Delta R_2'] & U_2'(y) & y(1-y)[-\alpha x S_2 + (1-\mu)(-1+x)\Delta R_2'] \\ z(1-z)(\alpha y S_1 - \beta I y - \alpha S_1) & z(1-z)(\alpha x S_1 - \beta I x + R - \alpha S_2) & U_3'(z) \end{vmatrix} \quad (17)$$

In view of the fact that the asymptotic stable solution of the multigroup evolutionary game dynamic replication system must be a strict Nash equilibrium solution, the evolutionary system has eight pure strategy equilibrium points, which are $E_1(0,0,0)$, $E_2(0,0,1)$, $E_3(0,1,0)$, $E_4(1,0,0)$, $E_5(0,1,1)$, $E_6(1,0,1)$, $E_7(1,1,0)$, and $E_8(1,1,1)$. These eight can be substituted into the Jacobian matrix to solve the matrix eigenvalues. The results are shown in Table 5.

According to the evolutionary game theory, when $Det(J) > 0, Tr(J)_i < 0$, an evolutionary stable state will be formed, i.e., the equilibrium point will approach the local gradual stable state. At that time, it is in an unstable state, i.e., the equilibrium point will not approach the local gradual stable state. When $Det(J) > 0, Tr(J)_i = 0$ or is uncertain, the equilibrium point is the saddle point, i.e., the equilibrium point is stable in one direction and unstable in the other direction.

4. Numerical Simulations

According to the literature, in terms of green building project collaborative innovation between suppliers and construction enterprises, the data are limited, and the statistical data used are difficult to obtain. According to the basic paradigm of research on simulation parameters in the literature [42–44], this paper consulted experts who study simulations in supply chain-related fields and carried out a simulation combined with the actual research scope. By reading domestic and foreign studies and using the mature interview design method, the corresponding universities, architectural research institutes, construction industries, and their suppliers were selected as the research objects of the interview. The main information included the personal information of the interviewees and the survey topics related to this study. Among the interviewees, 81.02% were male and 18.98% were female; 31% of the interviewees had a doctor's degree, 20.21% had a master's degree, and 17.84% had a bachelor's degree or below; 21.56% had worked for 5 years or less, 32.64% had worked for more than 5 years but less than 10 years, and 45.80% had worked for 10 years or more. The main questions asked during the interview were as follows: What are the influencing factors of suppliers' participation in collaborative innovation of green production films of construction enterprises? What role does the government play in the collaborative innovation of green building projects between suppliers and construction enterprises? What is the impact of government tax incentives, government infrastructure construction, and environmental pollution punishment on the collaborative innovation of green building projects between suppliers and construction enterprises?

In the process of suppliers' participation in the collaborative innovation of green building projects of construction enterprises, the dynamic evolution behavior of the three parties in the evolutionary game model involving the government, suppliers, and construction enterprises can be more truly described. In combination with the dynamic replication equations of the three parties involved in the game, the evolutionary trajectory of can be established, which can be processed using the discrete method.

Using the timestep Δt, the following equations can be derived:

$$\frac{dx(t)}{dt} \approx \frac{x(t+\Delta t) - x(t)}{\Delta t} \tag{18}$$

$$\frac{dy(t)}{dt} \approx \frac{y(t+\Delta t) - y(t)}{\Delta t} \tag{19}$$

$$\frac{dz(t)}{dt} \approx \frac{z(t+\Delta t) - z(t)}{\Delta t} \tag{20}$$

According to Equations (18)–(20), the evolution trajectory of the three players participating in the game was simulated using MATLAB. In order to more truly reflect the evolution status of the players, the values of other parameters were determined according to the actual situation of green building project collaborative innovation between suppliers and construction enterprises, and the corresponding strategies of the players were set to 0.5. A numerical simulation was used to analyze the dynamic evolution of the three parties in the game.

4.1. The Influence of Tax Preference α on Suppliers'Participation in the Evolutionary Game of Collaborative Innovation of Green Building Projects in Construction Enterprises

In order to make the simulation more objective, tax preferences were set as α = 0.2, 0.5, or 0.8; the corresponding evolutionary game simulation results are shown in Figure 1.

The government's tax incentives will continue to encourage suppliers to choose collaborative innovation. If the government's short-term tax incentives are small, construction enterprises will evolve in the direction of midway betrayal. When the government's long-term tax incentives are large, construction enterprises will evolve in the direction of collaborative innovation of green building projects, with the construction enterprises having greater enthusiasm for collaborative innovation of green building projects. The short-term preferential tax policy has no obvious stimulating effect on the level of green building project collaborative innovation of construction enterprises, mainly because the construction enterprises are not willing to make a large short-term investment in innovation. Driven by the effect of long-term preferential tax policies of the government, construction enterprises will continue to evolve toward the direction of collaborative innovation of green building projects, because they enjoy the dividend of preferential tax policies. In the collaborative innovation of green construction projects, in order to stimulate suppliers and construction enterprises to better carry out collaborative innovation of green projects, the government can formulate corresponding incentive policies such as early tax incentives, thereby actively promoting suppliers and construction enterprises to evolve toward the collaborative innovation of green building projects. In the early stage of the policy, the government can implement a large number of tax incentives or even reduce the corresponding tax, such as the implementation of 3–5 years of preferential tax relief. With the continuous tightening of the preferential tax policies of the government and the construction enterprises, the corresponding level of innovation will gradually improve. When green building projects in the construction industry become stable, while the green building project technologies of suppliers and construction enterprises are in a mature stage, the government should cancel the corresponding preferential tax policies.

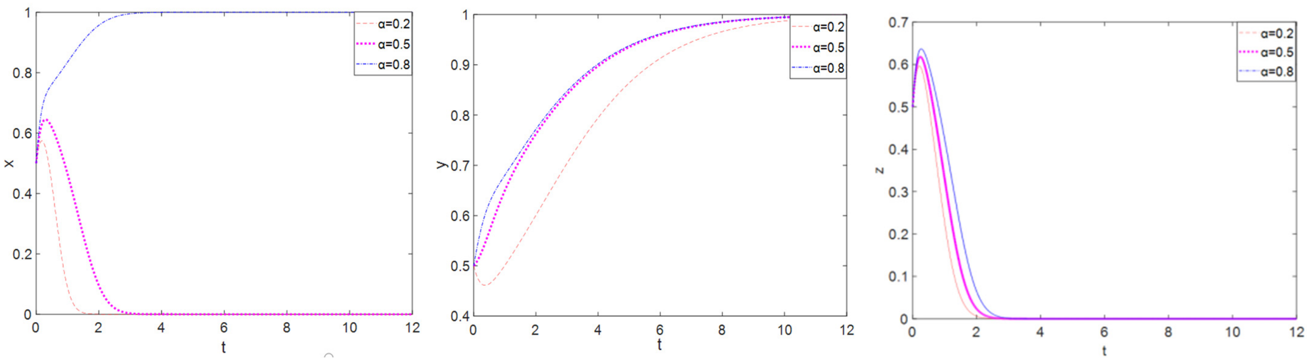

Figure 1. The influence of tax preference on the behavior of suppliers of collaborative innovation in green building projects of construction enterprises according to evolutionary game.

4.2. The Impact of Government Infrastructure Construction β on Suppliers' Participation in the Evolutionary Game of Collaborative Innovation of Green Building Projects in Construction Enterprises

In order to make the simulation more objective, the government infrastructure construction was set as β = 0.2, 0.5, or 0.8; the corresponding evolutionary game simulation results are shown in Figure 2.

The government's infrastructure support for suppliers to participate in collaborative innovation of green building projects of construction enterprises will encourage suppliers and construction enterprises to choose green building projects for collaborative innovation. With the continuous maturity of green building projects in the construction market, the government will take the opportunity to give up infrastructure construction and turn to other supporting policies. In order to support suppliers and construction enterprises to carry out collaborative innovation of green building projects, under different infrastructure construction efforts, the government can evolve from positive promotion to negative promotion. In order to stimulate the collaborative innovation and development of green building projects of suppliers and construction enterprises, the government can continuously increase the corresponding infrastructure construction for green building project innovation. For example, a green development foundation of the construction industry and a green collaborative innovation cooperation platform can be established. The government will continue to strengthen the construction of collaborative innovation infrastructure, so as to improve the resource supply in the process of collaborative innovation and enhance the performance of collaborative innovation. When the green building project innovation of suppliers and construction enterprises develops to a certain extent, the government should weaken or even reduce the corresponding infrastructure construction until completely withdrawing from the corresponding infrastructure construction.

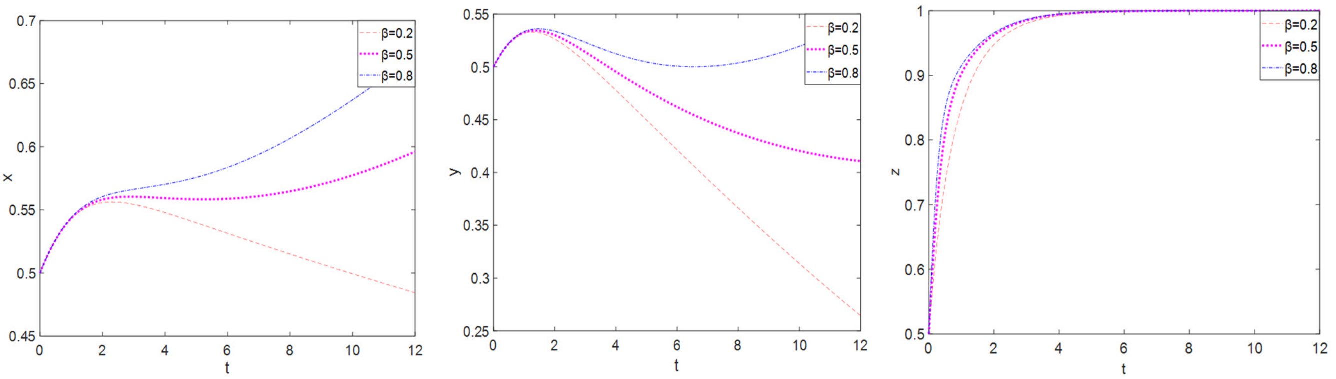

Figure 2. The impact of government infrastructure construction on the behavior of suppliers of collaborative innovation in green building projects of construction enterprises according to evolutionary game.

4.3. The Influence of Environmental Pollution Punishment on Supplier's Participation in Evolutionary Game Behavior of Green Building Project Collaborative Innovation of Construction Enterprises

In order to make the simulation more objective, the environmental pollution penalty was set to γ = 0.2, 0.5, or 0.8; the corresponding evolutionary game simulation results are shown in Figure 3.

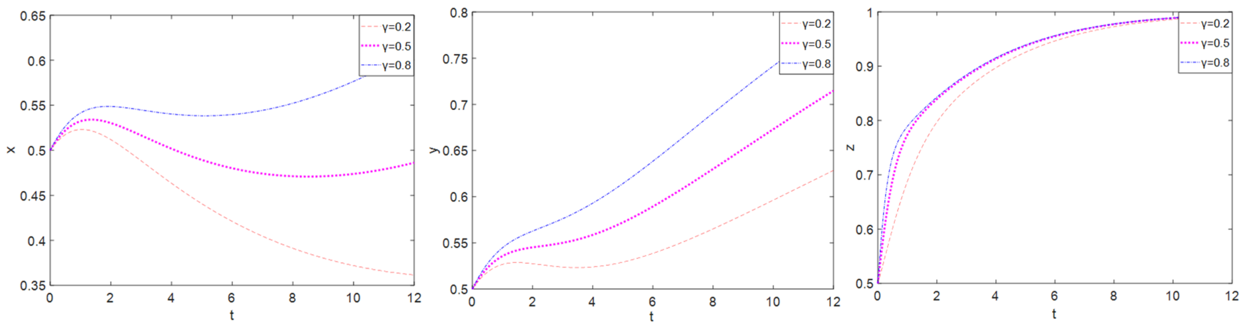

Figure 3. The impact of environmental pollution punishment on the behavior of suppliers of collaborative innovation in green building projects of construction enterprises according to evolutionary game.

A low-intensity environmental pollution punishment can hardly encourage construction enterprises to evolve toward collaborative innovation, whereas a medium-intensity environmental pollution punishment can encourage construction enterprises to evolve toward collaborative innovation, and a high-intensity environmental pollution punishment can encourage construction enterprises to choose the direction of midway betrayal. The environmental pollution punishment has no significant impact on suppliers' selection of green building project collaborative innovation in the short term. In the construction market, the means of environmental pollution punishment are through the collection of pollution discharge fees, environmental administrative penalties, financial expenditures for environmental protection, and the promulgation of environmental laws and regulations. The low-intensity environmental pollution punishment has no significant impact on the collaborative innovation of green building projects of construction enterprises. With the medium-intensity environmental pollution punishment, construction enterprises will continue to improve their R&D level and promote their green building project innovation. A high-intensity environmental pollution punishment prevents the construction enterprises from conducting green building project innovation. The high intensity is too much for the construction enterprises to bear, which affects the enthusiasm of the construction enterprises for green technology innovation. In the short term, environmental pollution punishment has no significant impact on suppliers' choice of green building project collaborative innovation.

5. Conclusions and Implications

Following early investigations based on limited rational game theory, this study constructed an evolutionary game model of suppliers' participation in green building project collaborative innovation of construction enterprises under government governance, before running a simulation using MATLAB according to the actual situation. In the development process of green building projects in the construction industry, the government plays the role of promoting collaborative innovation. Through government guidance, a mutual benefit can be established among the government, construction enterprises, and suppliers, thus achieving the innovation and cooperation goal of green building projects in the construction industry. The results show that the government's tax preference will continue to encourage suppliers to choose collaborative innovation. If the government's short-term tax preference is small, the construction enterprises will evolve toward midway betrayal. If the government's long-term tax preference is large, the construction enterprises will evolve toward collaborative innovation of green projects, and the construction enterprises have a high enthusiasm for collaborative innovation of green building projects. Furthermore, the government's support for suppliers' participation in the infrastructure construction of green building project collaborative innovation of construction enterprises will encourage suppliers and construction enterprises to choose green building project collaborative innovation. With the continuous maturity of green building projects in the construction market, the government can evolve from active governance to passive governance. The government can take the opportunity to give up infrastructure construction and turn to other supporting policies. Lastly, a low-intensity environmental pollution punishment can hardly encourage construction enterprises to evolve toward collaborative innovation, whereas a medium-intensity environmental pollution punishment can encourage construction enterprises to evolve toward collaborative innovation, and a high-intensity environmental pollution punishment can encourage construction enterprises to choose the direction of midway betrayal. Environmental pollution punishment has no significant impact on suppliers' selection of green building project collaborative innovation in the short term.

In order to improve the collaborative innovation research and development of green building projects in the construction market, countermeasures should be put forward. First, the strategic height of green building development should be further enhanced, preferential tax policies should be reasonably formulated, and the steady development of the green building market should be promoted. Second, the government can build an efficient sharing and transfer platform for green building technology, promote the rapid transformation of green building scientific and technological achievements, and maximize the benefits of the integration and allocation of green project resources in the construction industry. Third, a government governance mechanism that combines punishment with incentives should be implemented to thoroughly establish a green development strategy.

As the collaborative innovation of green building projects in construction enterprises is a complex behavior involving the interests of many subjects, several aspects will be studied in the future. First, the strategy selection mechanism of various game players under the influence of government subsidies, cost sharing, and other factors will be discussed, while deeply analyzing the driving factors of collaborative innovation of green building projects in construction enterprises. Second, the risk preference behavior of different subjects will be introduced, and the strategy choice of decision-makers under different risk preferences will be studied to deeply analyze the potential risk factors of collaborative innovation of green building projects in the construction market. Third, factors such as civic initiatives, driven by demands and energy prices, will be considered.

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