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Research Article

Stochastic Evolutionary Game Analysis on the Strategy Selection of Green Building Stakeholders from the Perspective of Supply-Demand Subject Populations

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In construction industry, the research and development (R&D) and application of green building technologies (GBTs) are crucial to promote the development of green buildings. From the perspective of supply-demand subject populations, this paper discusses the dynamic evolution process of strategy between individuals within construction enterprise populations and between construction enterprise populations and consumer populations. Firstly, based on Moran process, the stochastic evolutionary game model of construction enterprises adopting independent innovation strategy was constructed to obtain the conditions for the dominance of independent innovation strategy. Next, the bimatrix game model of construction enterprise populations and consumer populations was constructed to obtain the equilibrium frequency of the joint strategy. Then, the influence laws of the change of parameters on game were discussed through numerical simulations. The results show that (1) reducing the cost of independent R&D cost, reducing the spillover effect coefficient, increasing the loss of technology introduction, and increasing R&D subsidies for independent innovation construction enterprises are all conducive to IIS becoming an evolutionary stable strategy. (2) The marginal effect of IIS increases with the decrease in the spillover effect coefficient, the increase in the loss of technology introduction of construction enterprises, and the increase R&D subsidies. (3) The smaller the mutation rate is, the greater the cross-price sensitivity coefficient is, the greater the green sensitivity coefficient is, the greater the probability of government active encouragement is, and the more dominant (production of green buildings, purchase of green buildings) is. Finally, relevant measures and suggestions are proposed.

1. Introduction

Traditional buildings produce a large amount of greenhouse gases such as carbon dioxide during construction, operation, and demolition resulting in carbon emissions from construction industry being one of the major sources of carbon emissions from global economic activities [1]. In 2017, global CO_2 emissions from construction accounted for nearly 40 per cent of total CO_2 emissions from global economic activities [2]. Carbon reduction actions in construction industry are conducive to reducing greenhouse gas emissions. Unlike traditional buildings, green buildings reduce carbon emissions and alleviate building pollution, which can effectively respond to global climate change [3]. However, there are some problems in green building market, such as immature technology, low public willingness to purchase and imperfect management system etc. [4]. The development of green building market is jointly promoted by the strategic selection of stakeholders such as government, construction enterprises, and consumers. Focusing on GBTs, the development process of green building market is also the process of R&D and application of green building technology. Green building market development is localized [5]. The change in the number of enterprises and consumers choosing to produce and purchase green buildings affects the scale of the overall green buildings market. From the actual situation, the construction enterprise populations and the consumer populations are two finite populations. Moreover, the two groups are in an uncertain environment of green building market, and the players' strategy selections are influenced by random factors, which may lead to strategy mutation. Therefore, it is necessary to consider the influence of random factors, strategy selection intensity, group size, and other factors on the group strategy selection process.

The development of green building is a game process between the government, construction enterprises, consumers, and other stakeholders. Most research literatures regard the government as one of the game players and analyze the impact of government policies on the strategic choice of various stakeholders, such as the impact of environmental policies on the adoption of green building technology by alliance construction enterprises composed of building material enterprises and building material developers [6]; the influence process of subsidy coefficient, market supervision intensity and other factors on the green technology innovation strategy of enterprises [7]; the impact of positive and negative policy incentives on the green transformation of PPP-BR [8]; and the influence process of different reward and punishment mechanisms on the behavior evolution of suppliers and demanders in the green building market [9].

In terms of research methods, Moran process and bimatrix analysis are commonly used. Moran process is divided into three steps: selection, reproduction, and replacement [10]. Souza et al. and Nishimura et al. introduced the Moran process based on the dominant probability into evolutionary game [11] and described the birth-and-death process of individual selection in frequency-dependent Moran process [12]. Different from the deterministic evolutionary games, the stochastic evolutionary games introduce selection intensity. According to the dependence between fitness and individual payoffs, the selection is divided into strong selection and weak selection. When the strategy has no mutation, the indicators for judging the overall evolutionary dynamics are divided into fixation probability [13] and fixation time [14]. Traulsen et al. propose an exponential mapping form suitable for strong selection and weak selection based on linear mapping form [15]. When the strategy has mutation, it is judged by average abundance. Some scholars analyzed dominant conditions for strategy to fixate when selection intensity is different [16]. The stochastic evolutionary game dynamics of bimatrix games can be described as frequency-dependent Moran process with mutation [17]. Most of the existing researches supplement and perfect the theoretical model of bimatrix game, such as introducing quantile to define the preference of stochastic payoff values and discuss the stationary distribution of the proposed birth-and-death process and the long-term equilibrium of $2 * 2$ bimatrix game evolution model; describing an algorithm for computing the approximate mixed Nash equilibrium in bimatrix games [18]; and proposing the expected loss averse Nash equilibrium, the optimistic loss averse Nash equilibrium, and pessimistic loss averse Nash equilibrium and their existence theorems [19]. Some scholars improve model from the perspectives of heterogeneity of learning mechanism [20], individual emotion type [21], and ambiguity of gains [22].

To sum up, at present, most research literatures think that the construction enterprise populations or consumer populations are infinite populations, while ignoring the actual situation that the number of populations is limited, and related research has not considered the influence of random factors, populations' size, and other parameters on the strategy selection process of players. This paper analyzes the random evolution process of group strategy selection based on the R&D and application of GBTs. Among them, the R&D stage mainly analyzes the behavior evolution process within the supply-side group, and the application stage mainly analyzes the behavior evolution process of the supply-side and demand-side groups.

2. Materials and Methods

2.1. Model Parameters and Related Assumptions

2.1.1. Model Parameters. The model parameters are shown in Table 1.

2.1.2. Basic Assumptions

(1) Basic Assumptions of Green Building Technology in R&D Stage.

Suppose there are M mixed and homogeneous construction enterprises in market. Each construction enterprises' R&D of GBTs can be divided into two options: independent innovation or technology introduction, respectively, denoted as $\{\alpha_{11}, \alpha_{12}\}$. Simplify the construction enterprise group with different strategies into two players with different strategies.

Assuming that the construction enterprises that choose the independent innovation strategies (IIS) have to pay the independent innovation cost C_1, the probability of technical R&D failure is f, and the probability of R&D success is $1 - f$. When technology R&D fails, independent innovation construction enterprises suffer from cost, time, and other losses is W_1. When R&D is successful, construction enterprises transfer technology patents at the probability of y_4 and transfer gains V_2; with the probability of $1 - y_4$ chooses not to transfer, get retained earnings V_1. Enterprise independent R&D suffered time window loss is W_3. When two construction enterprises choose independent innovation, they collaborate with a probability of y_6; the benefits of cooperation received by both construction companies choose to cooperate are V_4. Appropriate government subsidies to construction enterprises that choose independent R&D innovation which can encourage construction enterprises to carry out independent technological innovation and improve the technological development level of the construction industry. The probability of government active encouragement is y_3, and the R&D subsidies for construction enterprises that choose IIS are V_5. The construction enterprises that choose the technology introduction strategy (TIS) need to pay the cost C_2, $C_1 > C_2$. Gains after technology introduction are V_3. The technology introduced by construction enterprises

Table 1: Model parameters.

Parameter symbol	Parameter meaning	Parameter range
M	Number of construction enterprises	
α	Construction enterprise group	
β	Consumer group	
y_1	Cross price sensitivity coefficient	0-1
y_2	Green sensitivity coefficient of consumers	≥0
y_3	Probability of positive encouragement by the government	
y_4	Probability of transferring technology patents	
y_5	Spillover effect coefficient of one party's independent innovation and the other party's technology introduction	0-1
y_6	Cooperation probability when enterprises independently innovate	
y_7	Spillover effect coefficient when enterprises choose technology introduction	0-1
N, Z	Group size	
C_1	Independent innovation cost	$C_1 > C_2$
C_2	Technology introduction cost	
C_{g1}	Cost of green building for construction enterprises	$C_{g1} > C_{g2}$
C_{g2}	Operating costs paid by consumers after purchasing green buildings	$C_{g2} > C_{b2}$
C_{b1}	Cost of ordinary construction of enterprises	
C_{b2}	Operating costs paid by consumers after purchasing ordinary buildings	
f	Probability of technology R&D failure	
W_1	Time window loss	
W_2	Loss of technology introduction	
W_3	Time window loss of independent R&D of enterprises	
V_1	Retained earnings	
V_2	Transfer income	
V_3	Gain from technology introduction	
V_4	Cooperation income	
D_g	Green building demand	
D_b	General building demand	
V_g	Consumers' gains from buying green buildings	
V_b	Consumers' gains from buying ordinary buildings	
P_g	Sales price of green buildings	
P_b	Sales price of ordinary buildings	
G_1	Development subsidies for construction enterprises to develop green buildings	
G_2	Development subsidies for consumers to buy green buildings	
F	Carbon tax of enterprises from producing ordinary buildings	
h	Green degree of construction products	>0
a	Green building demand	≥0
u	Probability of strategy mutation in construction enterprise	
v	Probability of strategy mutation by consumers	
r	Market reputation gained by construction enterprises in producing green buildings	

is affected by the technology spillover effect, resulting in the loss of leading power of some industries, which is called the technology introduction loss. The loss of technology introduction is W_2. The selection of technology introduction by construction enterprises is influenced by the technology spillover effect of independent R&D enterprises, which is expressed by the spillover effect coefficient. The larger the spillover effect coefficient is, the larger the spillover effects are. The spillover effect coefficient is y_5 when one player innovates independently and the other player introduces technology. And the spillover effect coefficient is y_7 when both players choose to introduce technology.

(2) Basic Assumptions of Green Building Technology in the Application Stage.

Denote the number of consumers and construction enterprises are finite populations, the population' size as Z and N, respectively. Consumers face two strategic choices: buying green buildings (BGB) or buying ordinary buildings (BOB). The consumer populations are denoted as β, and the set of feasible strategies is denoted as $\{\beta_1, \beta_2\}$. Consumers have a rigid demand for buildings; they will choose to buy ordinary building or green building when they do not buy the desired type of building product: green building or ordinary building. Construction enterprises have two pure strategy choices: (1) producing green building (PGB) through independent innovation or technology introduction and (2) using the original production technology to produce ordinary buildings (POB). The construction enterprise populations are denoted as α, and its set of feasible strategies is denoted as $\{\alpha_1, \alpha_2\}$. No mixed strategies are considered [23].

Referring to the linear demand function model of product price in supply chain management research [24], the demand functions of green building and ordinary building are, respectively:

$$D_g = a - P_g + y_1 P_b + y_2 h, \tag{1}$$

$$D_b = \lambda a - P_b + y_1 P_g. \tag{2}$$

D_g and D_b, respectively, refer to the demand for green buildings and ordinary buildings. a refers to the demand for green buildings, $a \geq 0$. The selling price of the green building is P_g, and the selling price of the ordinary building is P_b. y_1 refers to the cross-price sensitivity factor, $y_1 \in (0, 1)$. The greater the y_1, the greater the competition, and the greater the impact of the selling price of its own product on demand compared to that of competing products. y_2 refers to the greenness sensitivity coefficient of consumers, $y_2 \geq 0$. The larger the y_2, the more sensitive the consumer is to the greenness of the building product, and the higher the consumer's green preference is; the smaller the y_2, the lower the consumer's green preference. h refers to the greenness of construction products, $h \geq 0$. λ refers to the difference between the potential demand for green buildings and ordinary buildings. The demand for green buildings is greater when $0 < \lambda < 1$. When $\lambda = 1$, the demand for green buildings and ordinary buildings is equal. The demand for ordinary buildings is greater when $\lambda > 1$.

When construction enterprises choose to produce green buildings, it may be produced by independent innovation or technology introduction. When they choose independent R&D, it needs to pay costs on R&D; when they choose technology introduction, it needs to spend a lot of money to purchase patents, etc. These possible costs are called development costs. Construction enterprises pay development costs of C_{g1} to produce green buildings and C_{b1} to produce ordinary buildings, where $C_{g1} > C_{b1}$. Consumers receive the benefit V_g when they purchase green buildings, and the benefit V_b when they purchase an ordinary buildings. Running costs refers to the costs paid for heating, etc. Consumers who buy green buildings pay running costs C_{g2} , and those who buy ordinary buildings pay running costs C_{b2}, where $C_{g2} < C_{b2}$. To promote the development of the green building market, the government will actively encourage construction enterprises to produce green buildings and consumers to buy green buildings through subsidies and strong regulation. Suppose the probability that the government actively encourages is y_3, the subsidy to construction enterprises is G_1, the subsidy to consumers is G_2, and the carbon tax F is levied on enterprises producing ordinary buildings. Construction enterprises producing green buildings will gain market reputation r.

2.2. Model Building

2.2.1. Model Building of Green Building Technology in R&D Stage. The game payment matrix within the construction enterprise group in the R&D stage is shown in Table 2.

Suppose there are l construction enterprises within the groups of construction enterprises choosing strategy α_{11} and $M - l$ construction enterprises choosing strategy α_{12}. Combined with Table 1, the expected payoffs of construction enterprises choosing α_{11} and $\alpha_{12}(E_l^{\alpha 11}, E_l^{\alpha 12})$ are obtained as shown in Equations (1) and (2), where $l = 1, 2, 3, \cdots M - 1$.

$$\begin{aligned} E_l^{\alpha_{11}} &= \frac{l-1}{M-1}\{-C_1 + (1-f)[y_4 V_2 + (1-y_4)V_1] - fW_1 - W_3 + y_6 V_4 + y_3 V_5\} \\ &\quad + \frac{M-l}{M-1}\{-C_1 + (1-f)[y_4 V_2 + (1-y_4)V_1)] - fW_1 - W_3 + y_3 V_5\}, \\ E_l^{\alpha_{12}} &= \frac{l}{M-1}\{-C_2 + y_5 V_3 - W_2\} + \frac{M-l-1}{M-1}\{-C_2 + y_7 V_3 - W_2\}. \end{aligned} \tag{3}$$

Denote selection intensity ω as stochastic factors. The uncertain environment faced by construction enterprises is divided into two situations: expected payoffs dominated and stochastic factors dominated. Under the expected payoff dominates, the fitness is completely determined by the expected return; under the stochastic factor dominates, the expected payoffs has little effect on the fitness.

The relationship between fitness and payoff function is exponential mapping, and the fitness of construction enterprises selection α_{11} and $\alpha_{12}(f_l^{\alpha 11}, f_l^{\alpha 12})$ are:

$$f_l^{\alpha_{11}} = \exp\left[\omega * E_l^{\alpha_{11}}\right], \tag{4}$$

$$f_l^{\alpha_{12}} = \exp\left[\omega * E_l^{\alpha_{12}}\right], \tag{5}$$

where $\omega \geq 0$. Suppose there is no mutation in game. Based on the probability transfer formula and the total probability

Table 2: Game payoff matrix of construction enterprise populations.

Strategy selection		Construction enterprise 2	
		IIS (y)	TIS ($1-y$)
Construction enterprise 1	IIS (x)	$(-C_1 + (1-f)[y_2 V_2 + (1-y_4)V_1] - fW_1 - W_3 + y_6 V_4 + y_3 V_5,\ -C_1 + (1-f)[y_2 V_2 + (1-y_4)V_1] - fW_1 - W_3 + y_6 V_4 + y_3 V_5)$	$(-C_1 + (1-f)[y_2 V_2 + (1-y_4)V_1] - fW_1 - W_3 + y_6 V_4 + y_3 V_5, -C_2 + y_5 V_3 - W_2)$
	TIS ($1-x$)	$(-C_2 + y_5 V_3 - W_2, -C_1 + (1-f)[y_2 V_2 + (1-y_4)V_1] - fW_1 - W_3 + y_6 V_4 + y_3 V_5)$	$(-C_1 + y_7 V_3 - W_2, -C_1 + y_7 V_3 - W_2)$

formula, the probability of α_{11} and α_{12} fixates $(\rho_{\alpha 11}, \rho_{\alpha 12})$ are:

$$\rho_{\alpha_{11}} = \left\{ \sum_{k=0}^{M-1} \exp\left\{ \frac{\omega}{2} k(k+1) \frac{-y_6 V_4 + y_5 V_3 - y_7 V_3}{M-1} + \omega k \frac{y_6 V_4 + (M-1)\{C_1 - (1-f)[y_4 V_2 + (1-y_4)V_1] + f W_1 + W_3 - y_3 V_5 - C_2 + y_7 V_3 - W_2\}}{M-1} \right\} \right\}^{-1},$$
$$\rho_{\alpha_{12}} = \left\{ \sum_{k=0}^{M-1} \exp\left\{ \frac{\omega}{2} k(k+1) \frac{-y_6 V_4 + y_5 V_3 - y_7 V_3}{M-1} + \omega k \frac{(M-1)\{-C_1 + (1-f)[y_4 V_2 + (1-y_4)V_1] - f W_1 - W_3 + y_6 V_4 + y_3 V_5 + C_2 + W_2\} + (y_7 - M y_5) V_3}{M-1} \right\} \right\}^{-1}. \tag{6}$$

After a long period of evolution, the strategy used by the player with a large fixation probability is more likely to become an evolutionary stable strategy [25]. The strategy α_{11} is more likely to become evolutionary stable strategy when $\rho_{\alpha 11} > \rho_{\alpha 12}$; the strategy α_{12} is more likely to become evolutionary stable strategy when $\rho_{\alpha 11} < \rho_{\alpha 12}$.

2.2.2. Model Building of Green Building Technology in the Application Stage. The game payoff matrix between the construction enterprise populations and the consumer populations is shown in Table 3.

In the basic step of updating, each individual of populations α interacts with each individual of populations β to generate payoffs. When individual i in population α interacts with individual j in population β, the expected payoffs of individual i are a_{ij}, and that of individual j is b_{ij}. The payoff matrix is.

$$(A, B) = \begin{matrix} & \beta_1 & \beta_2 \\ \alpha_1 & (a_{11}, b_{11}) & (a_{12}, b_{12}) \\ \alpha_2 & (a_{21}, b_{21}) & (a_{22}, b_{22}) \end{matrix} \tag{7}$$

The expected benefits of each interaction of construction enterprises are $F_{\alpha_i} = \sum_{i=1}^{2} a_{ij} y_j$, $i = 1, 2$. The expected benefits of each interaction of construction enterprises are $F_{\beta_j} = \sum_{j=1}^{2} b_{ij} x_i$, $j = 1, 2$. There is an exponential mapping between the fitness and benefit functions. The fitness of the construction enterprises to adopt the strategy α_i is $f_{\alpha_i} = \exp\ (\delta * F_{\alpha_i})$, and the fitness of the consumer to adopt the strategy β_j is $f_{\beta_j} = \exp\ (\delta * F_{\beta_j})$. δ is the selection strength, $\delta \geq 0$.

2.3. Model Solution and Analysis

2.3.1. System Analysis of Green Building Technology R&D Stage Model

(1) Under the Expected Payoff Dominates.

Under the expected payoff dominates, construction enterprises are completely rational, and their strategic selection is entirely determined by expected payoffs and is not influenced by other factors. By comparing the difference of fitness in each state, the change of the number of construction enterprises adopting a certain strategy is analyzed. Let

$$h_l = f_l^{\alpha_{11}} - f_l^{\alpha_{12}}, l = 1, 2, 3, \cdots M - 1. \tag{8}$$

Take $l = 1$ and $l = M - 1$, respectively, and substitute Equations (1)–(5) into Equation (8), we get

$$h_1 = e^{\omega * E_1^{\alpha 11}} - e^{\omega * E_1^{\alpha 12}} = e^{\omega * \{-C_1 + (1-f)[y_4 V_2 + (1-y_4)V_1] - f W_1 - W_3 + y_3 V_5\}} - \mathrm{e}^{\omega * \left[-C_2 - W_2 + \frac{1}{M-1} y_5 V_3 + \frac{M-2}{M-1} y_7 V_3\right]},$$
$$h_{M-1} = e^{\omega * E_{M-1}^{\alpha 11}} - e^{\omega * E_{M-1}^{\alpha 12}} = e^{\omega * \left\{-C_1 + (1-f)[y_4 V_2 + (1-y_4)V_1] - f W_1 - W_3 + y_3 V_5 + \frac{M-2}{M-1} y_6 V_4\right\}} - \mathrm{e}^{\omega * (-C_2 + y_5 V_3 - W_2)}. \tag{9}$$

The game system may have the following situations:

(1) If $h_1 > 0$, selection behavior of construction enterprises supports α_{11} invading α_{12}, α_{11} is dominant; if $h_{M-1} < 0$, selection behavior supports α_{12} invading α_{11}, α_{12} is dominant

(2) If $h_1 > 0$ and $h_{M-1} > 0$ coexist, choose favorable α_{11} invading α_{12}, against α_{12} invading α_{11}, α_{11} is superior to α_{12}, and α_{11} is dominant

(3) If $h_1 < 0$ and $h_{M-1} < 0$ coexist, α_{12} will replace α_{11} as an evolutionary stable strategy

(4) If $h_1 < 0$ and $h_{M-1} > 0$ coexist, choose against α_{11} invading α_{12}, also against α_{12} invading α_{11}, and selection behavior of construction enterprises against change

(5) If $h_1 > 0$ and $h_{M-1} < 0$ coexist, the choice is conducive to α_{11} and α_{12} to invade each other, and selection behavior of construction enterprises tends to change

Proposition 1. *Under the expected payoff dominates, for M ≥ 2, there is $h_1 > 0$, $h_{M-1} > 0$, IIS becomes an evolutionary stable strategy when $(1-f)[y_4 V_2 + (1-y_4)V_1] + C_2 + W_2 + y_5 V_3 - C_1 - f W_1 - W_3 + y_3 V_5 - 2 y_7 V_3 > 0$.*

Proposition 1 shows that when the construction enterprise populations are completely rational, its strategy

Table 3: Game payoff matrix for the construction enterprise populations and the consumer populations.

Strategy selection		Consumer BGB (y)	Consumer BOB ($1-y$)
Construction enterprise	PGB (x)	$(D_g(P_g - C_{g1} + y_3hG_1 + r), D_g(V_g - P_g - C_{g2} + y_3hG_2))$	$(D_b(P_g - C_{g1} + y_3hG_1 + r), D_b(V_g - P_g - C_{g2} + y_3hG_2))$
	POB ($1-x$)	$(D_g(P_b - C_{b1} + y_3F - r), D_g(V_b - P_b - C_{b2}))$	$(D_g(P_b - C_{b1} + y_3F - r), D_b(V_b - P_b - C_{b2}))$

selection process is affected by parameters such as independent R&D cost, R&D failure rate, R&D failure loss, technology introduction loss, and R&D subsidies. Whether construction enterprises adopt IIS or TIS is closely related to their own income. When the profit of construction enterprises adopting IIS is greater than that of choosing TIS, construction enterprises tend to choose IIS.

(2) Under the Stochastic Factor Dominates.

Under the stochastic factor dominates, $\omega \longrightarrow 0$. Construction enterprises' strategy choice is influenced by policy orientation, decision-makers' preferences, and other factors in addition to expected payoffs. By discussing the change of the ratio of two fixation probabilities, this study analyzes the change of the number of groups choosing a certain strategy.

$$\begin{aligned}\frac{\rho_{\alpha_{12}}}{\rho_{\alpha_{11}}} = \prod_{l=1}^{M-1} \exp\left[\omega \sum_{l=1}^{M-1}\left(E_l^{\alpha_{12}} - E_l^{\alpha_{11}}\right)\right] = \exp\left\{-\omega\left\{\frac{M}{2}\{-2C_1\right.\right.\\ + 2(1-f)[y_4V_2 + (1-y_4)V_1] - 2fW_1 - 2W_3 + y_6V_4\\ + 2y_3V_5 + 2C_2 - (y_5+y_7)V_3 + 2W_2\} + \{C_1\\ - (1-f)[y_4V_2 + (1-y_4)V_1] + fW_1 + W_3 - y_6V_4\\ \left.\left. - y_3V_5 - C_2 + y_7V_3 - W_2\}\right\}.\end{aligned} \tag{10}$$

Proposition 2. *Under the stochastic factor dominates, the strategy α_{11} dominants when $-C_1 + (1-f)[y_4V_2 + (1-y_4)V_1] - fW_1 - W_3 + y_6V_4 + C_2 + y_5V_3 + C_2 - (y_5+y_7)V_3 + W_2 > 0$, IIS is more likely to become an evolutionary stable strategy.*

Proposition 2 shows that construction enterprises choosing IIS are closely related to independent R&D cost, R&D success rate, retained revenue after R&D success, transfer revenue, and R&D failure loss under the stochastic factor dominates. When the income of the enterprise choosing TIS is less than the income of IIS, the choice behavior supports IIS to invade TIS and then replaces TIS. IIS eventually becomes an evolutionary stable strategy.

Whether the situation is dominated by expected payoffs or by stochastic factors, the strategy choice of construction enterprises is related to parameters such as populations' size, cost of independent R&D, spillover effect coefficient, loss of technology introduction, and selection intensity. Under the expected payoff dominates, the benefits of construction enterprises in IIS are greater than those in TIS, the strategy choice of construction enterprises supports the invasion and replacement of TIS by IIS, and IIS dominates. Under the stochastic factor dominates, the gain of construction enterprises in TIS is smaller than the gain in IIS, and the strategy choice of construction enterprises resists the invasion of IIS by the TIS, and the IIS prevails. There is a threshold value for the number of construction enterprises choosing a certain strategy, and the populations' strategy changes when the number of construction enterprise populations exceeds the threshold value.

2.3.2. System Analysis of Green Building Technology Application Stage Model. Suppose there is mutation in strategy updating process. The probability of a mutation in construction firm's strategy is u and the probability of a mutation in consumer's strategy is v. Then, discuss the evolutionary process in neutral selection and weak selection cases.

Under the neutral selection, $\delta = 0$. It was calculated that $\langle x_i\rangle_0 = 1/2$, $\langle y_j\rangle_0 = 1/2$, and $\langle x_i y_j\rangle_0 = 1/4$. It is consistent with the results of Ohtsuki [17]. It is because the frequency of occurrence of any pair of strategy combinations of two populations under stochastic mutation conditions is expected to be the same in equilibrium.

In the case of weak selection, $\delta \longrightarrow 0$. The equilibrium frequencies of strategies α_1 and strategies α_2 adopted by construction enterprises are:

$$\begin{aligned}\langle x_1\rangle_\delta = \frac{1}{2} + \frac{\delta(Z-1)(1-u)}{8(1+Zu-u)}\left[\left(D_g + D_b\right)\left(P_g - C_{g1} + y_3hG_1\right.\right.\\ \left.\left. + r - P_b + C_{b1} + y_3F\right) + D_g r\right] + O\left(\delta^2\right),\\ \langle x_2\rangle_\delta = \frac{1}{2} - \frac{\delta(Z-1)(1-u)}{8(1+Zu-u)}\left[\left(D_g + D_b\right)\left(P_g - C_{g1} + y_3hG_1\right.\right.\\ \left.\left. + r - P_b + C_{b1} + y_3F\right) + D_g r\right] + O\left(\delta^2\right).\end{aligned} \tag{11}$$

The equilibrium frequencies of consumer populations adopting strategies β_1 and strategies β_2 are:

$$\langle y_1\rangle_\delta = \frac{1}{2} + \frac{\delta(N-1)(1-v)}{8(1+Nv-v)}\left[\left(D_g - D_b\right)\left(V_g - P_g - C_{g2} + y_3 h G_2 + V_b - P_b - C_{b2}\right)\right] + O\left(\delta^2\right),$$
$$\langle y_2\rangle_\delta = \frac{1}{2} - \frac{\delta(N-1)(1-v)}{8(1+Nv-v)}\left[\left(D_g - D_b\right)\left(V_g - P_g - C_{g2} + y_3 h G_2 + V_b - P_b - C_{b2}\right)\right] + O\left(\delta^2\right). \quad (12)$$

In the bimatrix games, the distribution of joint strategies is more concerned. The equilibrium frequencies of joint strategies in different cases are shown

$$\langle x_1 y_1\rangle_\delta = \frac{1}{4} + \frac{\delta}{16(u+v)(1+Zu-u)(1+Nv-v)} \cdot \{(Z-1)(1-u)\{v[1+(N-1)(u+v)]\pi_1 + 2u\pi_2\} + (N-1)(1-v)\{u[1+(Z-1)(u+v)]\pi_3 + 2v\pi_4\}\} + \mathrm{O}\left(\delta^2\right), \quad (13)$$

$$\langle x_1 y_2\rangle_\delta = \frac{1}{4} + \frac{\delta}{16(u+v)(1+Zu-u)(1+Nv-v)} \cdot \{(Z-1)(1-u)\{v[1+(N-1)(u+v)]\pi_1 + 2\mathrm{u}\pi_6\} + (N-1)(1-v)\{u[1+(Z-1)(u+v)]\pi_7 - 2v\pi_4\}\} + \mathrm{O}\left(\delta^2\right), \quad (14)$$

$$\langle x_2 y_1\rangle_\delta = \frac{1}{4} + \frac{\delta}{16(u+v)(1+Zu-u)(1+Nv-v)} \cdot \{(Z-1)(1-u)\{v[1+(N-1)(u+v)]\pi_9 - 2u\pi_2\} + (N-1)(1-v)\{u[1+(Z-1)(u+v)]\pi_3 + 2v\pi_{12}\}\} + \mathrm{O}\left(\delta^2\right), \quad (15)$$

$$\langle x_2 y_2\rangle_\delta = \frac{1}{4} + \frac{\delta}{16(u+v)(1+Zu-u)(1+Nv-v)} \cdot \{(Z-1)(1-u)\{v[1+(N-1)(u+v)]\pi_9 - 2u\pi_6\} + (N-1)(1-v)\{u[1+(Z-1)(u+v)]\pi_7 - 2v\pi_{12}\}\} + \mathrm{O}\left(\delta^2\right), \quad (16)$$

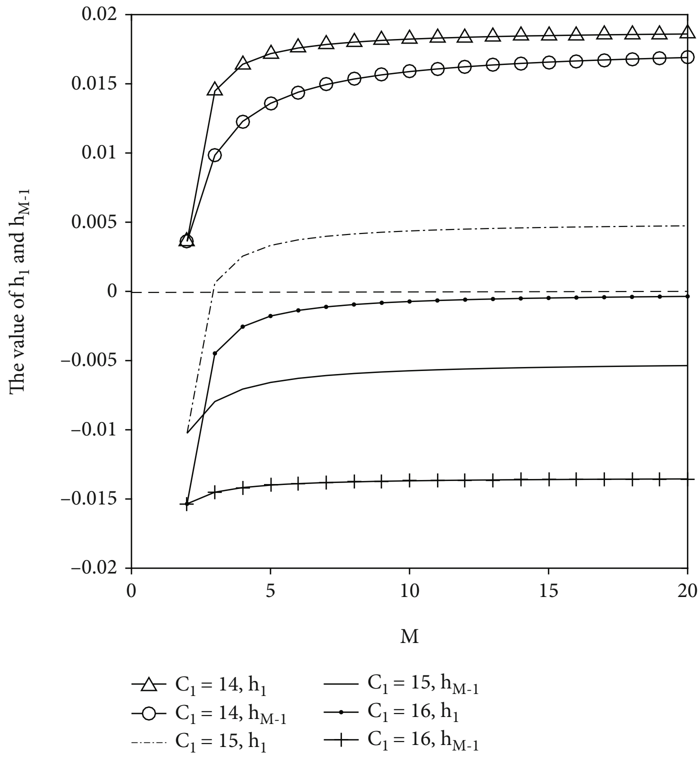
$F) + D_g r$, $\pi_2 = D_g(P_g - C_{g1} + y_3 h G_1 - P_b + C_{b1} + y_3 F + 2r)$, $\pi_3 = (D_g - D_b)(V_g - P_g - C_{g2} + y_3 h G_2 + V_b - P_b - C_{b2})$, $\pi_4 = (D_g - D_b)(V_g - P_g - C_{g2} + y_3 h G_2)$, $\pi_6 = D_b(P_g - C_{g1} + y_3 h G_1 - P_b + C_{b1} + y_3 F + r)$, $\pi_7 = (D_b - D_g)(V_g - P_g - C_{g2} + y_3 h G_2 + V_b - P_b - C_{b2})$, $\pi_9 = (D_g + D_b)(P_b - C_{b1} - y_3 F - r - P_g + C_{g1} - y_3 h G_1) - D_g r$, $\pi_{12} = (D_g - D_b)(V_b - P_b - C_{b2})$.

It can be seen that the strategy selection process of construction enterprise populations and consumer populations is related to parameters such as population' size, selection intensity, mutation rate, and price sensitivity coefficient. Due to the calculation formula of the equilibrium frequency of joint strategy is complex, therefore, numerical simulation is used to analyze the influence laws of population joint strategy in Section 4.3.

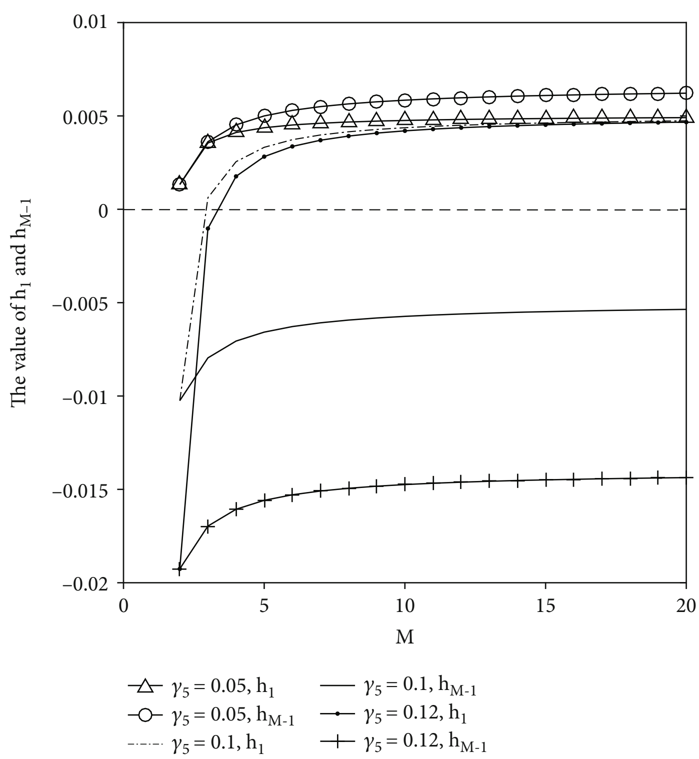
3. Results and Analysis

3.1. Stochastic Evolution Analysis of Strategy Selection of Construction Enterprise Populations in the R&D Stage of Green Building Technology. To present research results more intuitively, this paper uses numerical simulations to test the impacts of different parameter changes. The parameters are assigned: construction enterprises that choose IIS need to pay the cost of independent innovation of 15, the failure rate of technology R&D is 0.1, and suffer from R&D failure loss of 5. When the R&D is successful, the technology patent is transferred with a probability of 0.2, and the transfer gains 18; when it is not transferred, it gains self-retained earnings of 17. The probability of cooperation is 0.05 when all construction enterprises choose to innovate independently, and the gain from cooperation is 10. The probability of active government encouragement is 0.3, and the R&D subsidy for construction enterprises choosing the strategy of independent innovation is 4. Construction enterprises choosing the strategy of technology introduction need to pay the cost of technology introduction of 5, and the gain from technology introduction is 20; the loss from technology introduction after technology introduction is 1. The spillover coefficient is 0.1 when one side innovates independently and the other side introduces technology. The spillover coefficient is 0.01 when both sides choose technology introduction. Taking the group size, independent R&D cost, spillover effect coefficient, technology introduction loss, R&D subsidy, and other parameters of construction enterprises as variables, this paper analyzes the random evolution process of strategy selection of construction enterprises dominated by expected income and random factors. Under the expected payoff dominates, $\omega = 1$. Under the stochastic factor dominates, $\omega = 0.0001$.

3.1.1. Stochastic Evolution Process Analysis of Strategy Selection of Construction Enterprises under the Expected Payoff Dominates. The influence of the change of C_1 on the evolution path under the expected payoff dominates is shown in Figure 1(a). As can be seen from Figure 1(a) that when $h_1 < 0$, $h_{M-1} < 0$, $C_1 = 15$, and $2 \le M \le 4$, the selection behavior of construction enterprises supports the invasion of IIS by TIS. When $C_1 = 15$, and $M > 4$, the selection behavior is favorable to the mutual invasion of TIS of IIS. The hybrid strategy becomes an evolutionary stable strategy. As the cost of independent R&D decreases, both curves representing h_1 and h_{M-1} are located above $h_1 = 0$ or $h_{M-1} = 0$. At this time, $h_1 > 0$ and $h_{M-1} > 0$, IIS will replace TIS as the evolutionary stable strategy. When the cost of independent R&D increases, the two curves are located below $h_1 =$

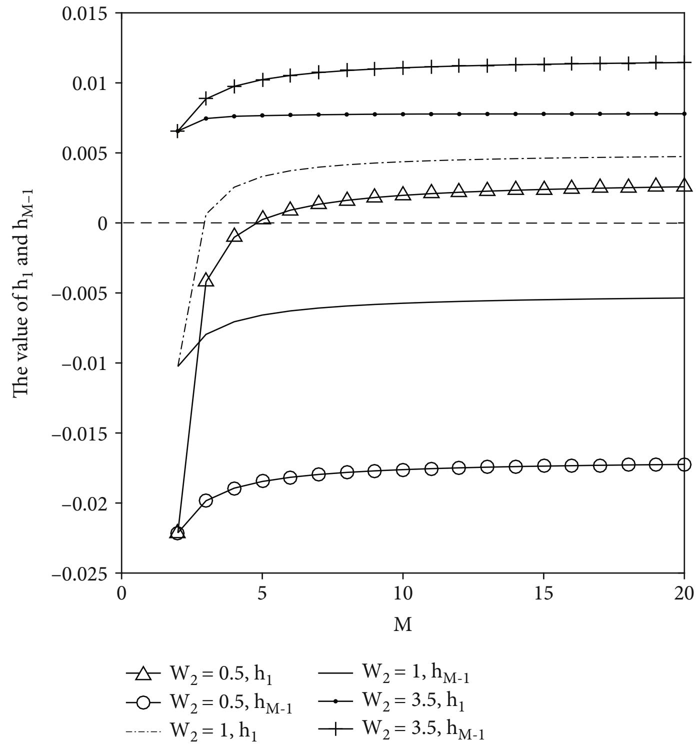


(a)

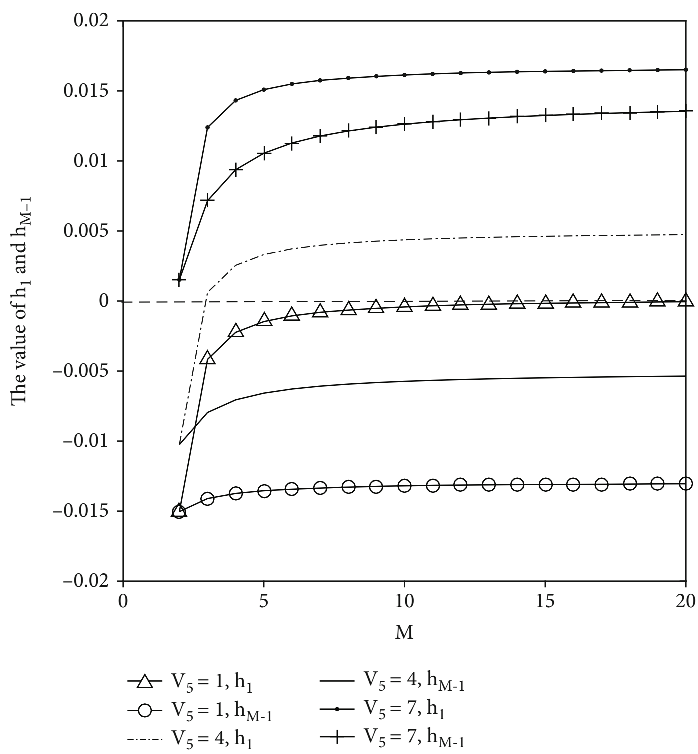


(b)

Figure 1: Continued.



(c)



(d)

Figure 1: (a) Influence of the change of C_1 on the evolution path under the expected payoff dominates. (b) Influence of the change of y_5 on the evolution path under the expected payoff dominates. (c) Influence of the change of W_2 on the evolution path under the expected payoff dominates. (d) Influence of the change of V_5 on the evolution path under the expected payoff dominates.

0 or $h_{M-1} = 0$, and TIS replaces IIS as the evolutionary stable strategy. It indicates that the threshold value of IIS to become evolutionary stable strategy increases. When the group's size of construction enterprises exceeds the

threshold value, some enterprises choose technology introduction, and some enterprises choose independent innovation, and a situation of two strategies coexists. When the cost of independent R&D decreases, IIS prevails and is more likely to become evolutionary stable strategy.

The influence of the change of y_5 on the evolution path under the expected payoff dominates is shown in Figure 1(b). As can be seen from Figure 1(b), the greater the spillover effect coefficient, the greater the threshold value of the construction enterprise group's tendency to IIS. When the group's size is less than the threshold value, the TIS is dominant; when the group's size is larger than the threshold value, the hybrid strategy is more likely to become an evolutionary stable strategy. When the spillover effect coefficient decreases, $h_1 > 0$, $h_{M-1} > 0$, the choice behavior of construction enterprises supports IIS to replace the TIS; IIS eventually becomes evolutionarily stable strategy. The greater the spillover effect coefficient is, the stronger the negative external spillover effect is, which is prone to the situation that TIS dominates or technology introduction and independent innovation coexist.

The influence of the change of W_2 on the evolution path under the expected payoff dominates is shown in Figure 1(c). As can be seen from Figure 1(c) that when the technology introduction loss of construction enterprises increases, the two curves lie above $h_1 = 0$ or $h_{M-1} = 0$. The construction enterprise populations tend to choose IIS, and IIS is more likely to become evolutionary stable strategy. When the loss of technology introduction decreases, the threshold size of IIS to become an evolutionary stable strategy becomes larger, and the selection behavior of construction enterprises supports the invasion of IIS by TIS. When the populations' size is smaller than the threshold size, TIS becomes evolutionary stable strategy. When the populations' size is larger than the threshold size, the hybrid strategy becomes evolutionary stable strategy.

The influence of the change of V_5 on the evolution path under the expected payoff dominates is shown in Figure 1(d). As can be seen from Figure 1(d), the government's R&D subsidies for construction enterprises affect the strategic choice of construction enterprise groups. When R&D subsidies increase, $h_1 > 0$, $h_{M-1} > 0$, IIS is dominant. When the R&D subsidy decreases, the two curves is below $h_1 = 0$ or $h_{M-1} = 0$, and TIS is dominant. When R&D subsidies decrease, with the increase of group's size, the choice behavior of construction enterprises tends to changes, and the mixed strategy is more likely to become an evolutionary stable strategy. It can be seen that the threshold scale of IIS becoming evolutionary stable strategy decreases with the increase of R&D subsidies.

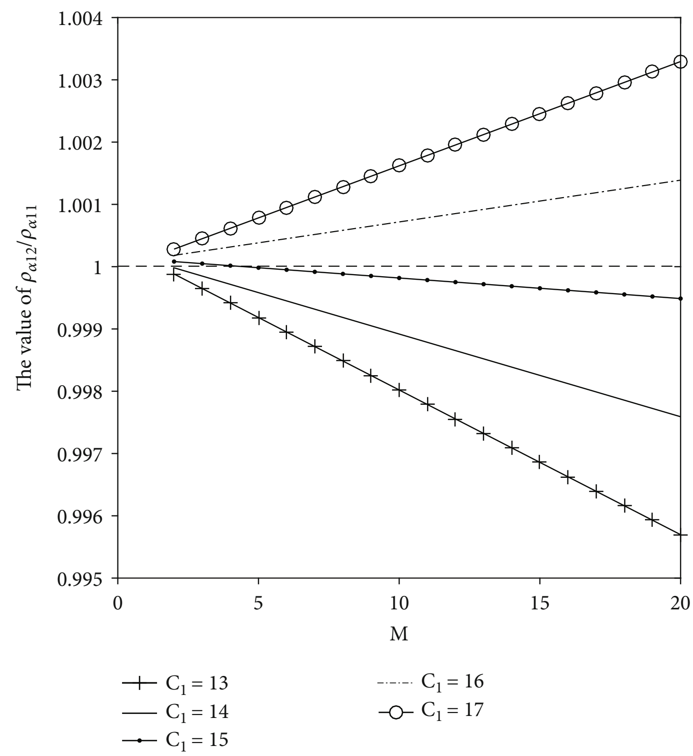
3.1.2. Stochastic Evolution Process Analysis of Strategy Selection of Construction Enterprises under the Stochastic Factor Dominates. The influence of the change of C_1 on the evolution path under the stochastic factor dominates is shown in Figure 2(a). As can be seen from Figure 2(a), in the initial state, when $C_1 = 15$, $2 \le M \le 6$, $\rho_{\alpha 12}/\rho_{\alpha 11} > 1$, that is, $\rho_{\alpha 12} > \rho_{\alpha 11}$, TIS becomes an evolutionary stable strategy. When $M > 6$, $\rho_{\alpha 12}/\rho_{\alpha 11} < 1$, namely, $\rho_{\alpha 12} < \rho_{\alpha 11}$, IIS becomes evolutionary stable strategy. When the cost of independent R&D increases, the curve representing the ratio of fixation probability is located above $\rho_{\alpha 12}/\rho_{\alpha 11} = 1$, $\rho_{\alpha 12} > \rho_{\alpha 11}$, the TIS is more likely to become an evolutionary stable strategy. When independent R&D cost decreases, $\rho_{\alpha 11} > \rho_{\alpha 12}$, IIS is more likely to become evolutionary stable strategy. With the reduction of enterprises' independent R&D cost, the distance of curve distance $\rho_{\alpha 12}/\rho_{\alpha 11} = 1$ becomes larger, and the threshold scale of IIS becomes evolutionary stable strategy which decreases, the advantage of IIS as an evolutionary stable strategy is more obvious.

The influence of the change of y_5 on the evolution path under the stochastic factor dominates is shown in Figure 2(b). As can be seen from Figure 2(b) that when spillover effect coefficient increases, the threshold scale of IIS becoming evolutionary stable strategy increases, and TIS is more dominant. The threshold scale of IIS becoming evolutionarily stable strategy decreases when the spillover effect coefficient decreases. The distance between curves representing fixation probability ratio and $\rho_{\alpha 12}/\rho_{\alpha 11} = 1$ increases with the decrease of spillover effect coefficient. Construction enterprise groups are more inclined to choose technology introduction. The spillover effect coefficient increases, the marginal effect of IIS decreases, and the marginal effect of TIS increases.

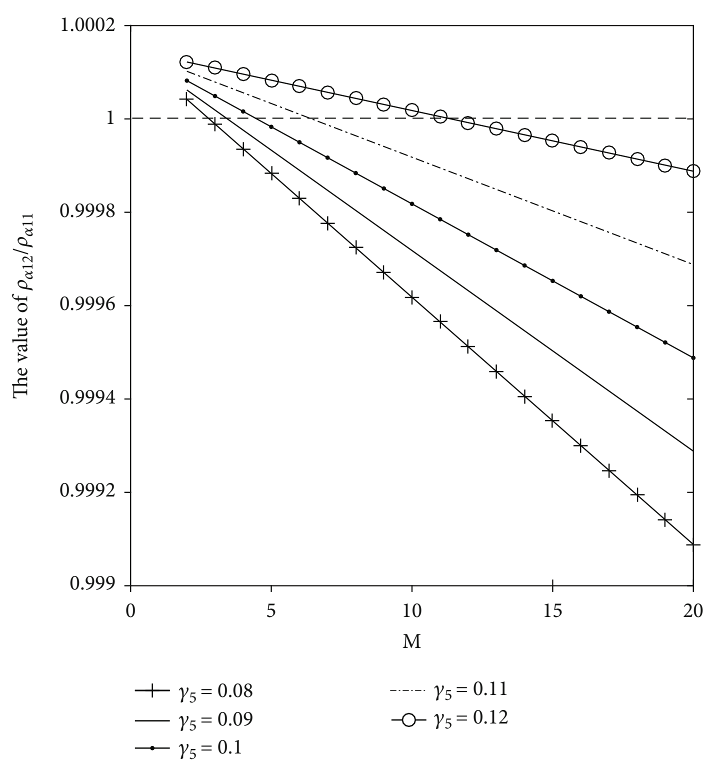
The influence of the change of W_2 on the evolution path under the stochastic factor dominates is shown in Figure 2(c). As can be seen from Figure 2(c) that when the technology introduction loss decreases, TIS is dominant. When the loss of technology introduction increases, IIS gradually dominates. The threshold scale of IIS becoming evolutionary stable strategy decreases with the increase of technology introduction loss. At the same time, it is also noted that the marginal effect of IIS increases when the loss of construction enterprises choosing TIS increases.

The influence of the change of V_5 on the evolution path under the stochastic factor dominates is shown in Figure 2(d). As can be seen from Figure 2(d), when the R&D subsidy is reduced, TIS is dominant; the smaller the R&D subsidy, the greater the distance between the curve representing the ratio of fixation probability and $\rho_{\alpha 12}/\rho_{\alpha 11} = 1$, and the more obvious the advantage of TIS is. When R&D subsidy increases, IIS gradually dominates. When the group's size of construction enterprises is constant, the greater the R&D subsidy of the government to independent innovation of construction enterprises is, the more dominant the IIS is. With the increase of group's size, the advantage of IIS becoming evolutionary stable strategy is more obvious. The threshold scale of construction enterprise groups choosing IIS to become evolutionary stable strategy decreases with the increase of R&D subsidies. Government R&D subsidies to construction enterprises increased, and the marginal effect of IIS increased.

3.2. Stochastic Evolution Analysis of Strategy Selection of Construction Enterprise Populations in the Application Stage of Green Building Technology. In order to describe the evolution process of the system to the ideal state more intuitively, take $x_1 y_1$ as an example for analysis. $x_1 y_1$ refers

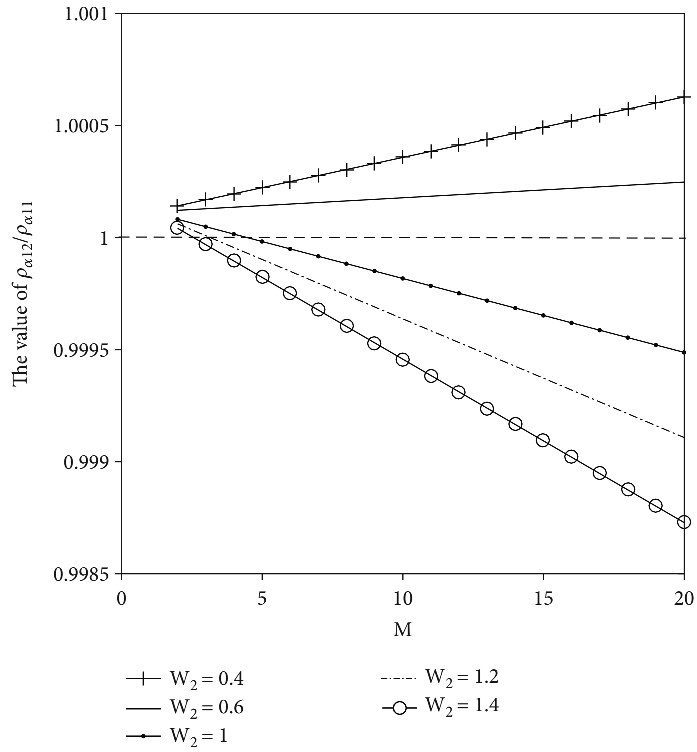


(a)

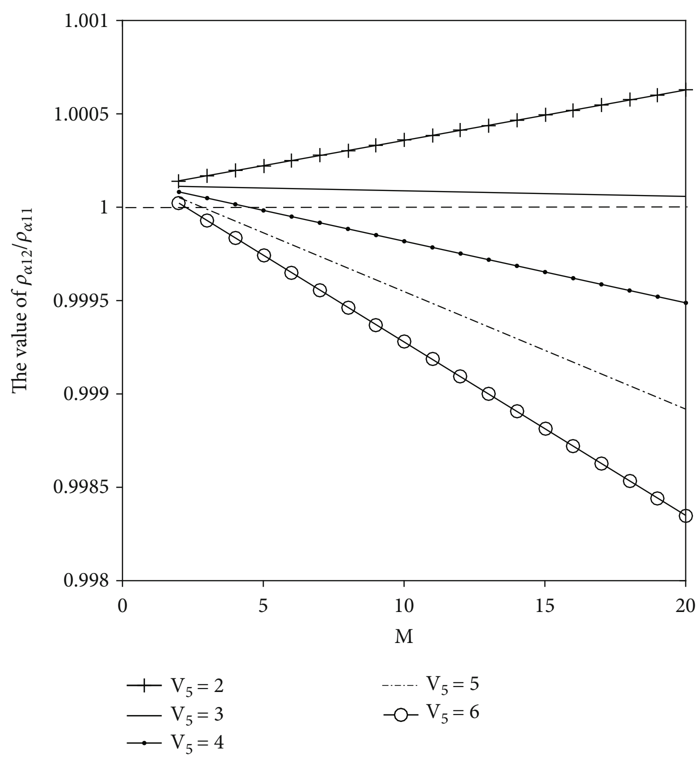


(b)

FIGURE 2: Continued.



(c)



(d)

Figure 2: (a) Influence of the change of C_1 on the evolution path under the stochastic factor dominates. (b) Influence of the change of y_5 on the evolution path under the stochastic factor dominates. (c) Influence of the change of W_2 on the evolution path under the stochastic factor dominates. (d) Influence of the change of V_5 on the evolution path under the stochastic factor dominates.

to the construction enterprise group choosing to produce green buildings and the consumer group choosing to buy green buildings. The parameters are assigned: the demand for green buildings is 40, and the sales price is 35; the sales

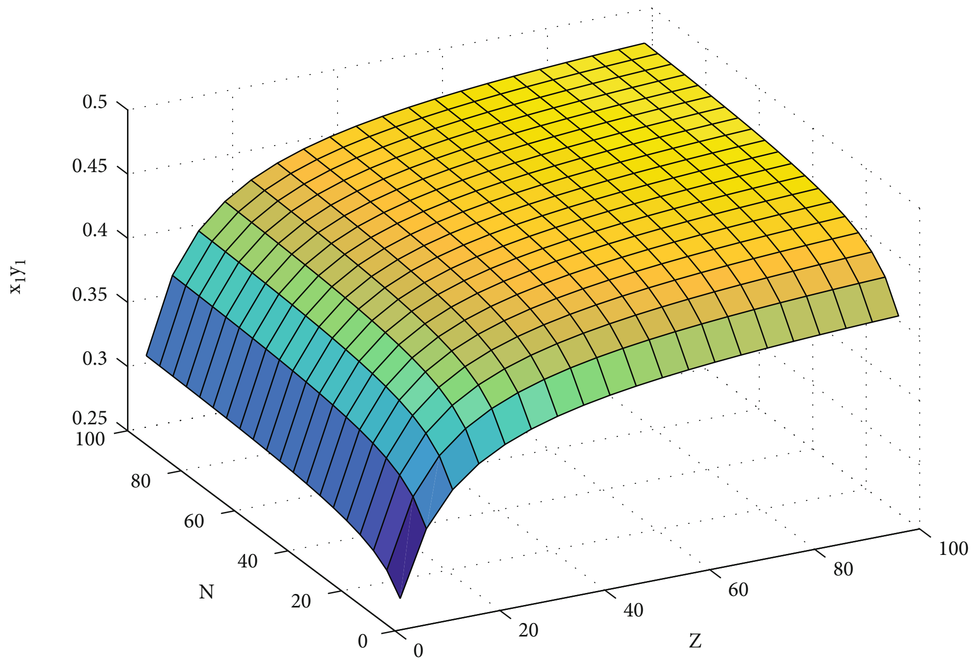


Figure 3: Changes in the equilibrium frequency of the joint strategy in the initial state.

price of ordinary buildings is 16. The cross price sensitivity coefficient is 0.5, the green degree sensitivity coefficient is 2.5, the green degree of building products is 3, and the potential demand difference between green buildings and ordinary buildings is 1.2. Construction enterprises need to pay 20 development costs to produce green buildings and 12 development costs to produce ordinary buildings. Consumers pay 25 for green building and 18 for ordinary building. Consumers pay 12 for green building and 21 for ordinary building. The probability of government active encouragement is 0.3, the development subsidy for construction enterprises is 20, the consumption subsidy for consumers to buy green buildings is 10, and the carbon tax is 12 for enterprises producing ordinary buildings. Construction enterprises R&D and sales of green building market reputation is 15. The probability of strategy mutation of construction enterprise groups and consumer groups is 0.1. The selection strength is 0.0001.

The change of the equalization frequency of the joint strategy in the initial state is shown in Figure 3. As can be seen from Figure 3, the equilibrium frequency of the joint strategy of (PGB, BGB) increases when the group's size of construction enterprises is certain and the group's size of consumers increases. When the consumer group's size is constant, the equilibrium frequency of the joint strategy of (PGB, BGB) increases with the increase of the construction enterprise group's size. The evolution speed of construction enterprises is greater than that of consumers. The equilibrium frequency of joint strategy increases with the increase of the scale of construction enterprise groups and consumer groups. This is because government's subsidies to construction enterprises and consumers increase the willingness of construction enterprises to produce green buildings and consumers to buy green buildings. The individual choice of construction enterprises has changed, and then, the development of the whole group has also been affected.

3.2.1. Analysis on the Influence of u and v Changes on the Evolution Path. As can be seen from Figure 4, when the strategic mutation rate of the construction enterprise populations and the consumer populations is reduced, the lower bound of the equilibrium frequency of joint strategy decreases from 0.25 to 0.2, and the upper bound increases from 0.5 to 0.7. The lower bound of the equilibrium frequency of the joint strategy increases from 0.25 to 0.255, but the upper bound decreases from 0.5 to 0.28 when the mutation rates increases. It shows that the range of equilibrium frequency of the joint strategy (PGB, BGB) decreases with the increase of mutation rate. Therefore, the smaller the mutation rate is, the more dominant (PGB, BGB) is. The threshold scale of joint strategy becoming evolutionary stable strategy increases with the increase of mutation rate.

3.2.2. Analysis on the Influence of y_1 Changes on the Evolution Path. As can be seen from Figure 5, when the cross price sensitivity coefficient decreases to 0.01, the lower bound of the equilibrium frequency of the joint strategy remains unchanged, and the upper bound decreases from 0.5 to 0.4. The lower bound of the equilibrium frequency of the joint strategy decreases from 0.25 to 0.2, and the upper bound increases from 0.5 to 0.6 when the cross-price sensitivity coefficient increases to 0.99. The equilibrium frequency of joint strategy increases with the increase of construction enterprises and consumers. The larger the price sensitivity coefficient is, the larger the threshold scale of joint strategy becoming evolutionary stable strategy is. Enterprises invest heavily in green building products in R&D and production, which leads to the price of green buildings being

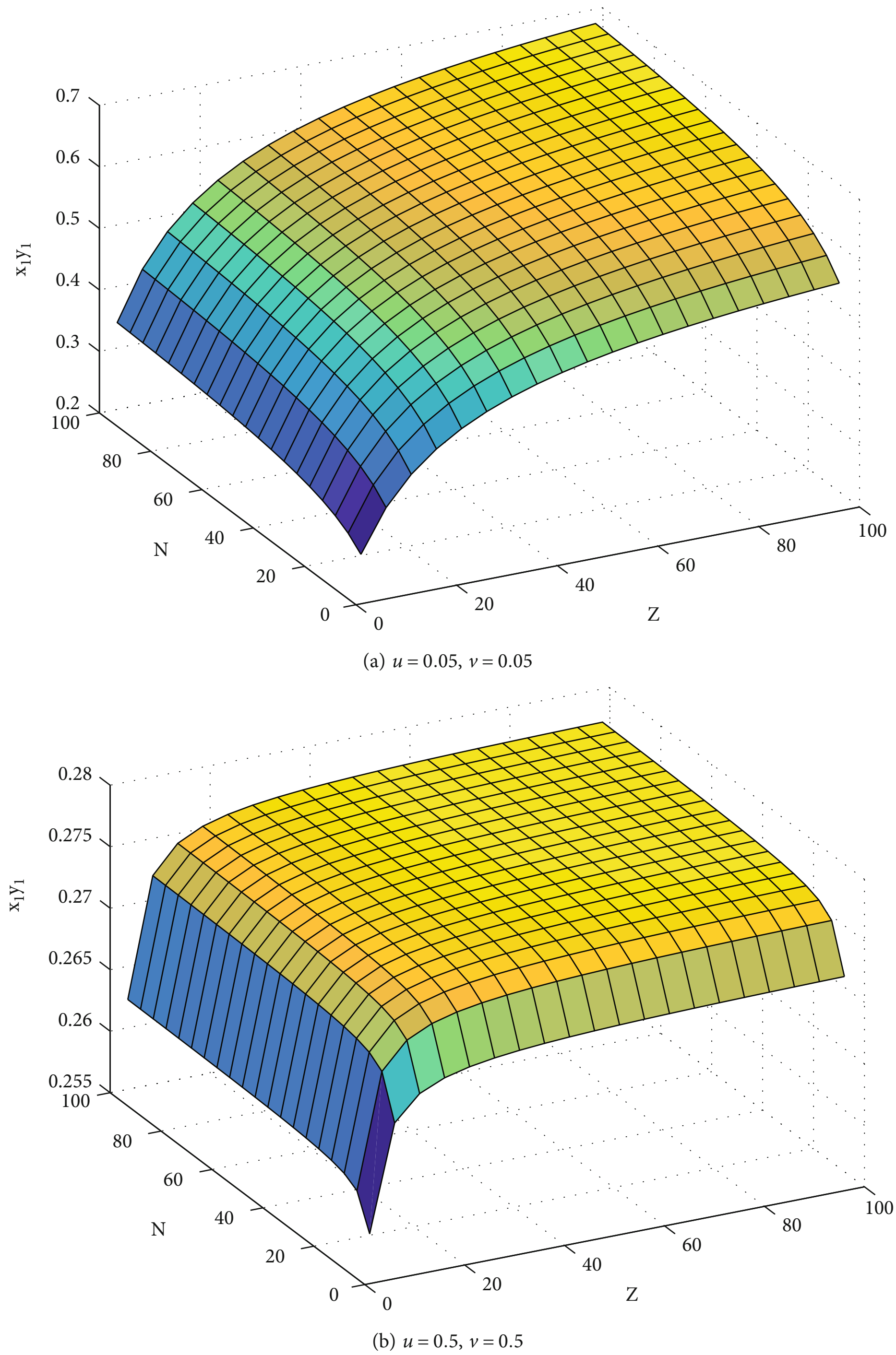
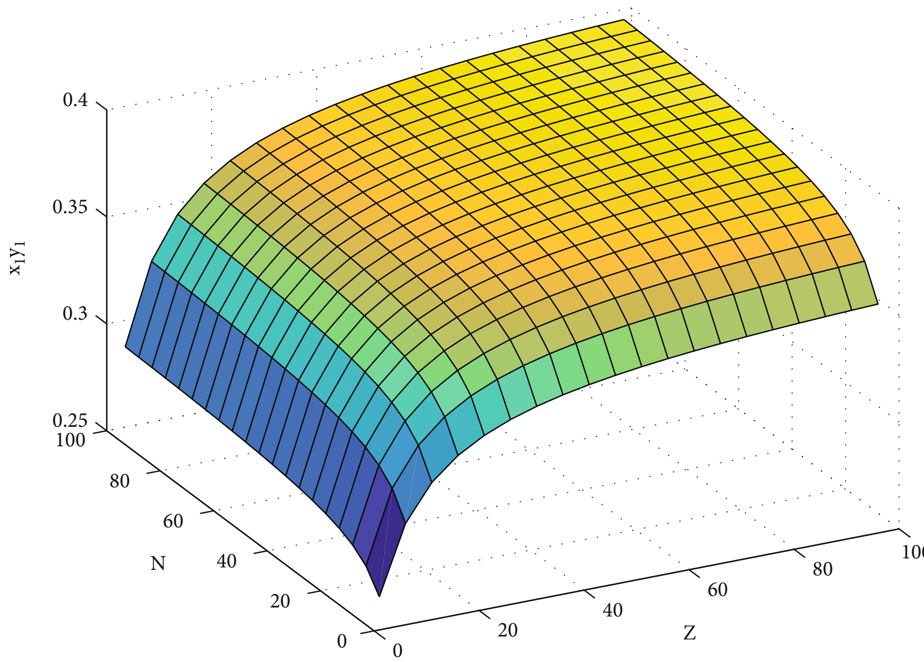


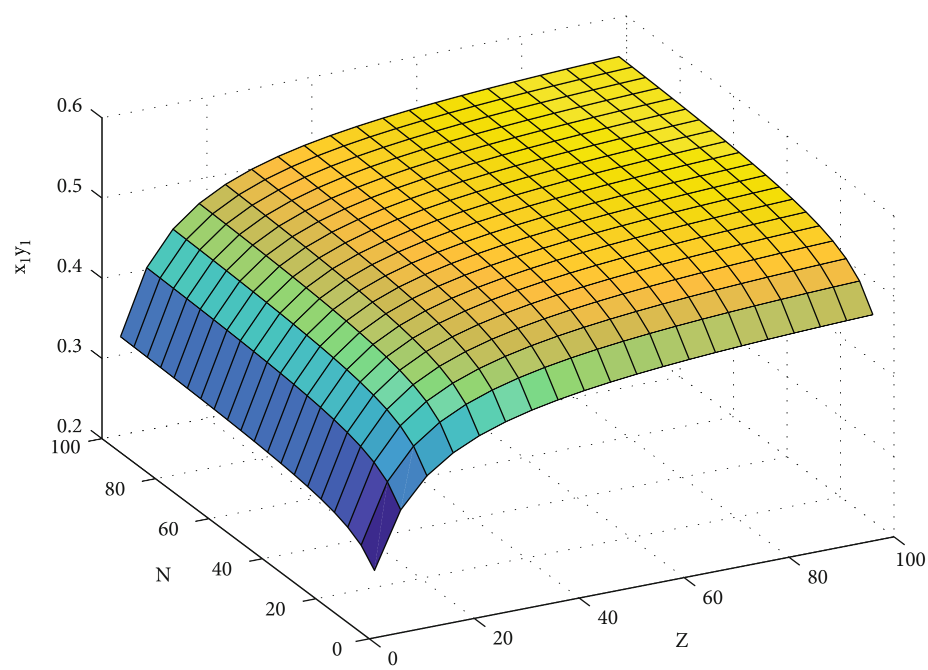
Figure 4: Influence of u and v changes on the evolution path.

higher than ordinary buildings, and consumers with high price sensitivity will reduce their willingness to buy green buildings. Construction enterprises that produce green buildings can reduce consumers' attention to prices through marketing strategies such as building product differentiation and building product uniqueness.

3.2.3. Analysis on the Influence of y_2 Changes on the Evolution Path. As can be seen from Figure 6, when the green sensitivity coefficient is reduced to 0.001, the consumer group's size is certain; with the increase of construction enterprise group's size, the equilibrium frequency of joint strategy is reduced from 0.4 to 0.35. The equilibrium frequency of joint strategy increases slightly with the increase of construction enterprise group's size. The lower bound of the equilibrium frequency of the combined strategy decreases from 0.25 to 0.2, and the upper bound increases from 0.5 to 0.6 when the green sensitivity coefficient increases to 12. When the green sensitivity coefficient changes, the change rate of construction enterprise group



(a) $y_1 = 0.01$

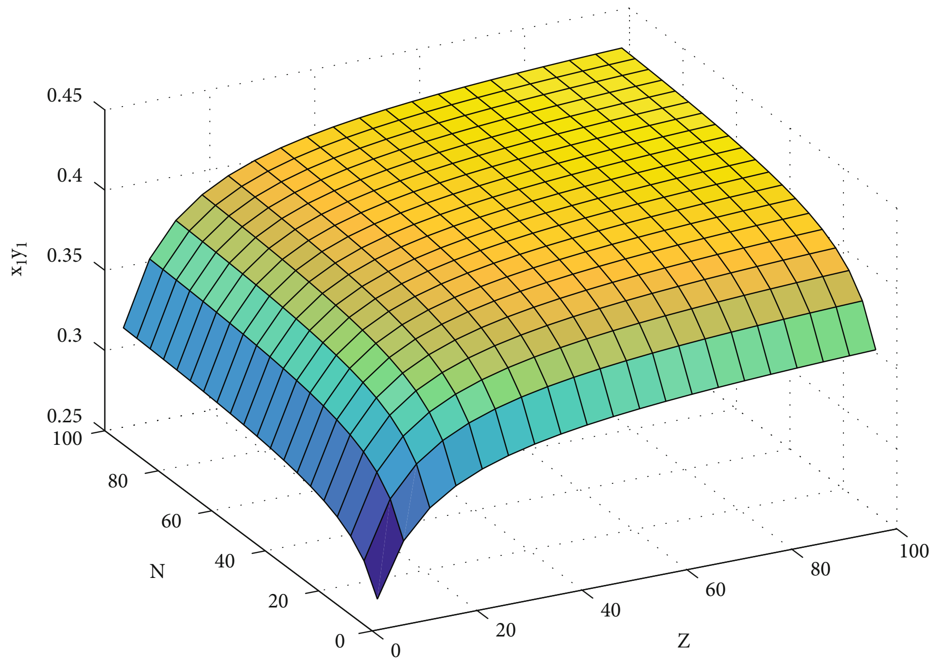


(b) $y_1 = 0.99$

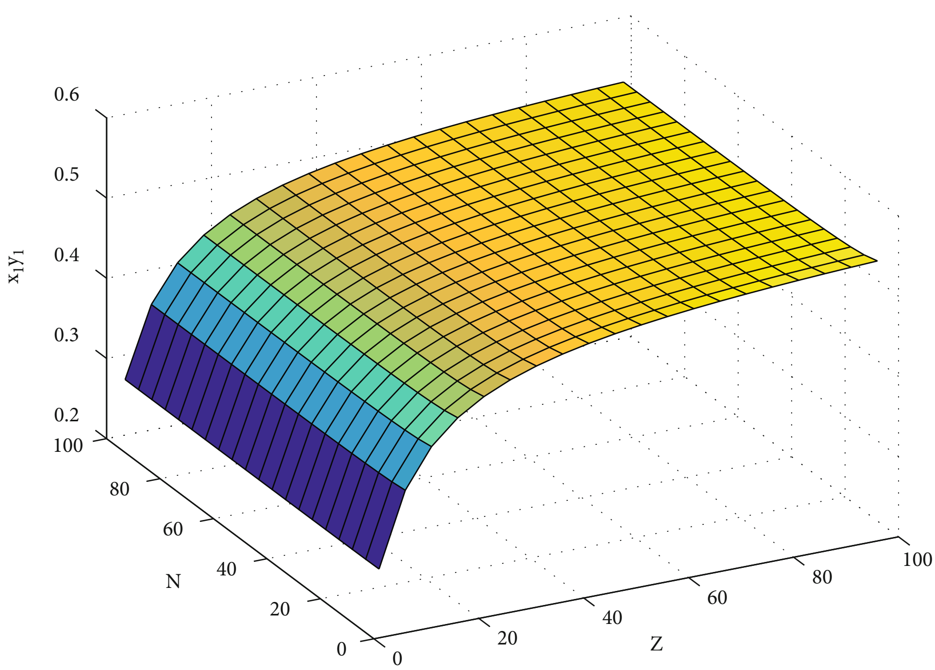
Figure 5: Influence of y_1 changes on the evolution path.

is significantly greater than that of consumer group. The larger the green sensitivity coefficient is, the larger the threshold scale of joint strategy becoming evolutionary stable strategy is.

3.2.4. Analysis on the Influence of y_3 Changes on the Evolution Path. As can be seen from Figure 7, when the probability of government active encouragement is reduced to 0.01, the scale of consumer groups is certain, and the frequency of joint strategy equilibrium decreases with the increase of the scale of construction enterprises. With a certain group's size of construction enterprises, the frequency of joint strategy equilibrium increases with the increase of the group's size of consumers. The lower bound of the equilibrium frequency of the joint strategy decreases from 0.25 to 0.2, and the upper bound increases from 0.5 to 0.7 when the probability of government active encouragement increases to 0.9. The government's behavior directly affects the strategic evolution of construction enterprise groups and consumer groups. And the threshold scale of (PGB,



(a) $y_2 = 0.001$

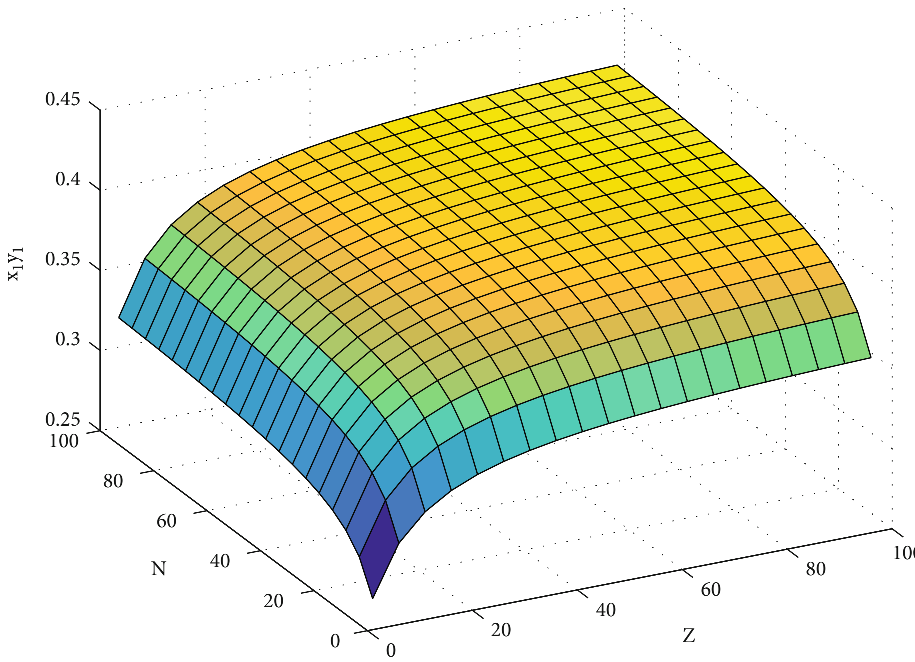


(b) $y_2 = 12$

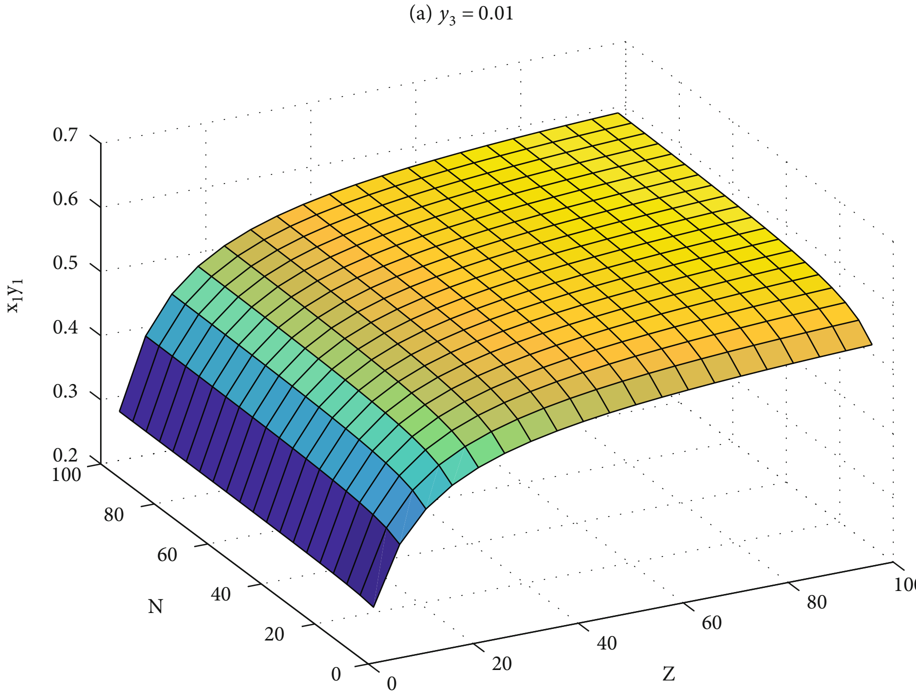
Figure 6: Influence of y_2 changes on the evolution path.

BGB) becomes evolutionary stable strategy increases with the increase of government active encouragement's probability.

3.2.5. Analysis on the Influence of G_1 and G_2 changes on the Evolution Path. As can be seen from Figure 8, the equilibrium frequency of joint strategy varies with government's subsidy. The equilibrium frequency of joint strategy increases with the increase of construction enterprise's scale and consumer group's scale when the government's subsidy increases. It shows that the government's subsidies to construction enterprise groups and consumer groups affect the group's strategy selection process. At the same time, the change of government's subsidy affects the joint strategy to become the threshold scale of evolutionary stable strategy. The greater the government's subsidy, the greater the threshold scale of coalition strategy becoming evolutionary stable strategy.



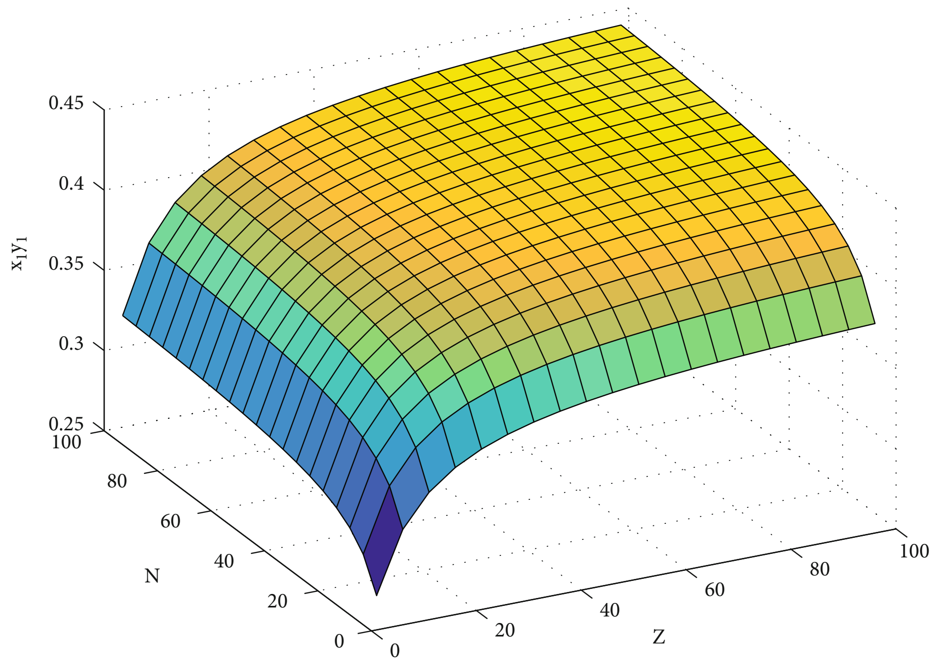
(a) $y_3 = 0.01$



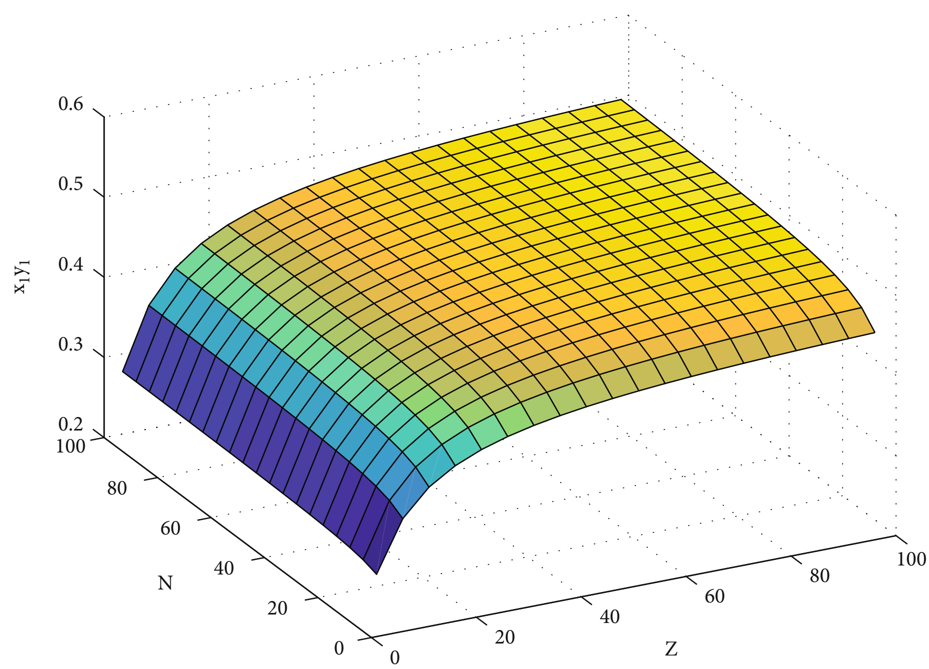
(b) $y_3 = 0.9$

Figure 7: Influence of y_3 changes on the evolution path.

3.2.6. Analysis on the Influence of F and r Changes on the Evolution Path. As can be seen from Figure 9, the carbon tax paid by construction enterprises to develop ordinary buildings decreases, the market reputation value of construction enterprises decreases, the scale of consumer groups remains unchanged, and the equilibrium frequency of joint strategies decreases significantly with the increase of the scale of construction enterprise groups. When the carbon tax paid by construction enterprises and their market reputation value increase, the scale of consumer group remains unchanged, and the equilibrium frequency of joint strategy increases with the increase of the scale of construction enterprise group. When the scale of construction enterprise group remains unchanged, and the carbon tax and market reputation value change, the law that the equilibrium frequency of joint strategy changes with the scale of consumer group is



(a) $G_1 = 5$, $G_2 = 1$



(b) $G_1 = 35$, $G_2 = 25$

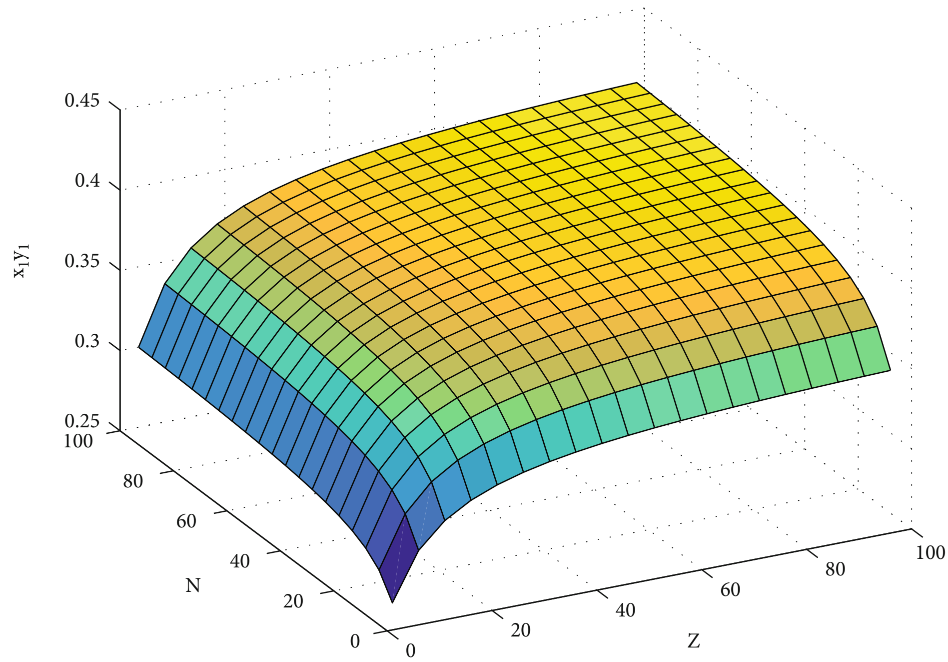
Figure 8: Influence of G_1 and G_2 changes on the evolution path.

not obvious. The threshold scale of (PGB, BGB) becomes evolutionary stable strategy increases with carbon tax and market credibility.

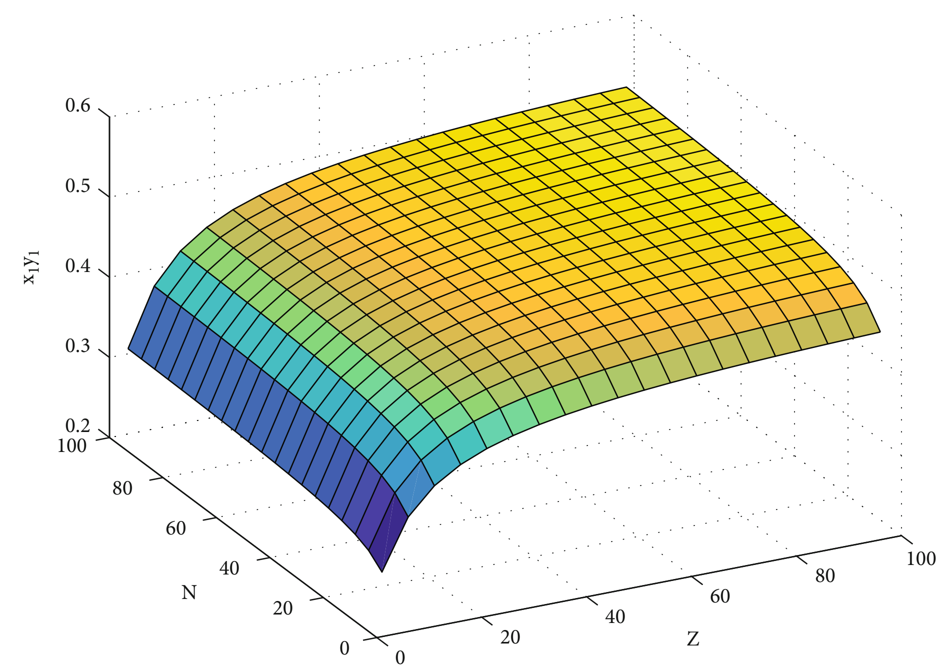
4. Discussions and Implications

4.1. Discussions. This study takes the R&D and application process of green building technology as the starting point and discusses the stochastic evolution of strategy selection of construction enterprises and consumer populations from the R&D stage and application stage, respectively, by using the methods based on Moran process analysis and bimatrix game analysis, and draws the following conclusions:

(1) In the R&D stage of green building technology, the government can appropriately reduce the R&D cost of enterprises by providing appropriate R&D subsidies to construction enterprises and improving the success rate of independent R&D of enterprises, so as to guide enterprises to choose independent



(a) $F = 6$, $r = 1$



(b) $F = 30$, $r = 20$

Figure 9: Influence of F and r changes on the evolution path.

innovation strategies, thus forms a virtuous circle through technological breakthroughs

(2) In the application stage of green building technology, the government encourages the construction enterprise populations and consumer populations to carry out green building production and consumption with a positive attitude. For example, increasing policy publicity to improve the public's green preference and green awareness; subsidizing construction enterprises and consumers who produce and purchase green buildings; levying carbon taxes on construction enterprises who produce ordinary buildings, etc., to reduce the mutation rate of the main population strategy, increase the threshold scale of construction enterprises producing green buildings and consumers purchasing green buildings; while promoting the development of green building market through the supply side, the demand of consumers on demand sides is boosted, which in turn stimulates the expansion of production on the supply side, forming a virtuous closed loop

(3) In the application stage of green building technology, the strategy selection process of construction enterprise groups and consumer groups is affected by the mutation rate, cross-price sensitivity coefficient, greenness sensitivity coefficient, the probability of active government encouragement, government subsidies, carbon tax, market reputation, etc. The smaller the mutation rate is, the greater the cross price sensitivity coefficient is, the greater the green degree sensitivity coefficient is, the greater the probability of government active encouragement is, and the more dominant (PGB, BGB) is

4.2. Implications

(1) The government should take the lead in improving the guidance and supervision mechanism, fully stimulate the power of construction enterprises to develop green building technology, minimize the externality of green building technology, and make up for the lack of market regulation

(2) The government should strengthen its support for independent R&D construction enterprises. High cost and high risk of independent R&D hinder the construction enterprises to choose independent innovation strategy. The government's subsidies for independent R&D construction enterprises reduce the cost of independent R&D, improve the enthusiasm of independent R&D, and expand the threshold scale for construction enterprises to choose independent innovation strategies as evolutionary stable strategy

(3) Construction enterprises should focus on improving their own R&D of technology. Improving the success rate of independent R&D of green building technology is the premise to promote independent R&D of construction enterprises. Construction enterprises can improve their R&D success rate by cultivating and introducing internal high-end talents and strengthening cooperation with professional research institutions

(4) The government should subsidize both construction enterprises and consumers. Due to the imperfect government supervision system and insufficient implementation of subsidy policy, the development of green building in China's construction market is slow. The government can increase consumers' demand for green buildings from the demand side by increasing policy propaganda and improving the public's green preferences and consumers' willingness to buy green buildings

(5) Establish a sound carbon tax system and information platform. Information platform increases the reputation exposure of construction enterprises, which directly affects the reputation and image of enterprises. The government levies carbon tax on construction enterprises that produce ordinary buildings, drives construction enterprises to produce green buildings through strong supervision, and increases the supply of green buildings

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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