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A Study on the Incentive Policy of China's Prefabricated Residential Buildings Based on Evolutionary Game Theory

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Abstract: With prefabricated construction method deemed as an effective way to improve the environmental performance and sustainable development of the building industry, it is inevitably adopted in the scaled residence in the process of residential industrialization. However, the development of prefabricated residential buildings is still immature under the current market economy system, because the stakeholders involved in the process are not yet able to form a good cooperation mechanism and they are more inclined to keep their own interests. As a result, the market share of prefabricated residential buildings is relatively low. Therefore, it is necessary to conduct research on the stakeholders involved. By analyzing their costs and benefits, the reasons that really impede the population of prefabricated residential buildings can be found. In this paper, incremental cost allocation coefficient is introduced, the incremental cost difference under different assembly rates is considered, and the allocation ratio of the incremental cost input of the prefabricated building is analyzed based on game theory. The evolutionary game theory for government and real estate companies is established under the condition of bounded rationality with consumer participation. Then the effectiveness of the game theory is verified using empirical analysis, so as to provide reference for the authorities to promote the large-scale development of prefabricated residential buildings.

Keywords: prefabricated building; incentive policy; evolutionary game model; incremental cost



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1. Introduction

Economic globalization and integration have led to the sustained and comprehensive development of the global economy, but behind this comprehensive economic development, many problems have emerged that are detrimental to the sustainable development of society [1]. The endless destruction of the natural environment and the unbridled demand for natural resources by humans have led to the uncontrolled spread of a series of environmental problems such as global warming, land desertification, marine environmental pollution, and air pollution, which have spread indiscriminately. Such environmental problems not only greatly restrict economic and social development but also threaten the living environment of mankind. To meet the needs of new urbanization construction and promote the upgrading and transformation of the construction industry, it is necessary to promote the development of prefabricated buildings in the industry since it conserves energy and reduces emissions. According to some studies, energy consumption for building construction accounts for 35–40% of the total energy consumption. The high energy consumption of the construction industry is a global problem. Furthermore, in China, the energy consumption of buildings accounts for 25–27% [2–4] of the total energy consumption. The energy consumption per unit area is more than twice that of developed countries. The Chinese government has now mandated that 15% of the country's annual new construction (in terms of floor area) be built in prefabricated buildings. At present, the Chinese government has stipulated that until the year of 2020, 15% (calculated by building area) of the newly

built buildings each year should be prefabricated buildings, and this will increase to 30% by 2025 [5]. In China, prefabricated building has been promoted vigorously. Promotion policies have been introduced everywhere, and requirements of the prefabricating rate of buildings have also increased year by year. Compared with the traditional cast-in-place concrete construction method, prefabricated buildings can achieve significant savings in terms of construction water, plastering mortar usage, building formwork, construction energy consumption, and construction waste due to the massive reduction in cast-in-place operations, which is of great significance in promoting the healthy development of the construction industry. The problems that have arisen in China's construction industry over the past year or two, particularly the "insane" increase in the price of sand and gravel and other construction materials in 2018, as well as the haze control that has caused many construction sites to stop working, cannot be explained by technical reasons alone but must be seen as an issue related to sustainable development. That is, China's reserves of resources and energy are likely lacking in meeting the needs of the development of China's construction industry. In the face of the environmental damage caused by the traditional building production methods and the continued downturn in the real estate market as well as China's energy conservation and environmental protection policy orientation, traditional building production methods are facing a major bottleneck and the real estate industry urgently needs to transform from extensive production to intensive and refined production and towards green, healthy, and sustainable prefabricated residential buildings [6]. However, the substantial factor that has hindered the development of prefabricated construction is that compared to traditional construction, the initial investment cost generated by prefabricated construction is higher. The increased costs are borne by the real estate enterprises alone, but the incremental benefits generated by these incremental costs, such as social and environmental benefits, are shared by the entire country and society [7]. This misalignment of input and income entities makes real estate enterprises unwilling to choose prefabricated construction. In the existing research, some loopholes and deficiencies still exist. First of all, the assembly rate is not introduced in the study of incentive mechanism of prefabricated residential building construction. Secondly, considering the problems occurring in the development of prefabricated residential buildings, most of the countermeasures and suggestions proposed by scholars are still not put into action. No efforts are made in analyzing interest conflicts of all participants. Therefore, in this research, a game theory is established based on the fact that all stakeholders involved share the incremental cost together while taking into account the consumer's willingness to buy and analyzing the incremental cost and benefit of different prefabricating rates. Through the analysis of the cost and benefit attracting attention from each participant, the law of strategy selection by both parties in the dynamic evolution environment is found. Based on ensuring interests of both sides, efforts should be made in advancing the development of prefabricated residential buildings, offering creative ways of relating incentive policy to governmental analysis and further improving related theories of promoting prefabricated residential buildings. Only in doing so can building industries develop in a sustainable manner.

2. Literature Review

2.1. Development of Prefabricated Buildings

At the beginning of the 20th century, the German architect Walter Gropius first proposed that the industrialization of buildings could be carried out economically and quickly. Its development has undergone a process from quantity to quality. In the last century during the 1950s and 1960s, it was the first developing stage. With the determination of the production system as the core, its aim was to solve the problem of housing shortage in Europe after World War II. It was a stage of quantitative change; in the 1970s and 1980s, it was the initial development period, with the focus on improving quality and realizing qualitative change. After the 1990s, it reached the late stage of development, focusing on further technological development. Lovell, H., et al. proposed that technological innovation could solve the contradiction between traditional construction methods and

prefabricated buildings [8]; Barriga, E.M., et al. also pointed out that applying the lean inventory and supply chain management theories of manufacturing to the material control of prefabricated residential buildings could bring substantial benefits to the prefabricated residential industry suggested [9]. In the later development stage, the explorations were more about the technological innovation and breakthroughs of prefabricated buildings. Some countries were facing the dilemma of large-scale promotion of prefabricated buildings, such as Malaysia. Yashiro T pointed out that in order to systematize the building system, standardize the design, and modernize the management, prefabricated residential buildings needed to be oriented to the market demand and be supported by scientific and technological progress [10]. Chiang, Y.H., et al. used regression analysis to analyze the contract value and the virtual variables representing various measures of public housing or institutional construction when studying the Hong Kong prefabricated construction market, and then pointed out that the prefabricated requirements themselves did not increase the obstacles to the construction. The major reasons that hindered market development were technological monopoly, imperfect industrial chain, lack of policies, and insufficient public awareness [11]. As for Sweden, the market development is rather successful. Through the existing literature, Hjort, B., et al. analyzed the factors for the success of industrialized buildings in Sweden, and it was believed that the development of the concept of residential industrialization, the realistic and systematic economic foundation, and knowledge and technology were the three key factors for success. They also pointed out that it was an effective way to promote the development of industrialized building concepts through cooperation with universities [12]. Based on the above development realities and the successful experience, researchers generally believe that in the early stages of development, the government should stimulate the enthusiasm of enterprises or consumers. Taxation was the most commonly used incentive policy. Cansino J M and other scholars introduced the tax incentives adopted by 27 EU members when promoting green energy [13]. Many countries have adopted government policies to stimulate market development. For example, the U.S. government has introduced a series of preferential industrial policies for consumers and enterprises in terms of financial systems, tax exemptions, and financial services. Japan provides low-interest long-term loans to enterprises, enacts tax breaks, sets up special financial public funds, and sets up technology development and industrial development subsidy systems.

2.2. Application of Evolutionary Game Theory

Game theory is widely used in the analysis and research of political, economic, and social behaviors. Rosas A believed that by increasing penalties or rewards, the cooperation mechanism established by the evolutionary game theory could achieve a stable equilibrium, which was more stable than considering any strategy separately [14]. Potochnik A believed that evolutionary game theory was more suitable for studying human social behavior. The rational thinking of the previous classic game theory has been replaced by natural selection, reflecting the evolution of social behavior [15]. Some scholars have also used game theory to study stakeholders in supply chain management and engineering. In the context of green supply chain management, Zhao, R., et al. used game theory to analyze the choices manufacturers made facing reducing materials and reducing carbon emissions. By leveraging the concept of “risk tolerance”, a basis was determined for reducing carbon emissions and environmental risks, then how manufacturers’ strategic choices would be affected by government penalties or rewards by including government policies in the supply chain was studied, and finally, the application prospects of game theory in supply chain management was illustrated through case studies [16]. Different from the static game from Rui Zhao, Tian, Y., et al. used the evolutionary game method to study the relationship between enterprises, governments, and consumers in the green supply chain. It is believed that the government’s economic incentives for enterprises and consumers’ understanding of environmental protection are the keys to development [17]. Liang, X., et al. used game theory to study the behavior of the stakeholders in the green transformation of buildings

and believed that the inconsistency of the stakeholders' interests and objectives was the reason why the project could not proceed smoothly. The complexity and uncertainty of coordination also aggravated the obstacles [18]. Cohen, C., et al. used game theory to analyze the strategic behaviors of consumers, developers, central governments, local governments, and non-profit organizations when promoting green buildings and put forward policy reform proposals to promote the construction of high-quality green buildings in Israel [19]. Barari, S., et al. established an evolutionary game model between producers and retailers to seek ways to maximize economic benefits when developing green products [20]. Qian, Q.K., et al. used the game tree to explore the game behavior of stakeholders in the green building market and proposed that the main factor hindering the development was the high transaction cost. The government should design more favorable incentives to reduce the transaction cost of green buildings and stimulate market investment by increasing the expected utility for real estate developers [21]. Chen, Q., et al. used game theory to analyze the interests of the government and the construction industry. By constructing a game model, the stability and feasibility of government policies in promoting prefabricated construction were discussed [22].

The literature research on the application of evolutionary games in building promotion is shown in Table 1.

Table 1. Research comparison of evolutionary game in building promotion.

The Author(s)	The Research Object	Players	Conclusion
Tian, Y., et al.	green supply chain	enterprises, governments, and consumers	The government's economic incentives for enterprises and consumers understanding of environmental protection are the key to development
Liang, X., et al.	green transformation of buildings	the behaviors of the building owners and occupiers	The inconsistency of the stakeholders' interests and objectives was the reason why the project could not proceed smoothly
Cohen, C., et al.	green buildings	consumers, developers, central governments, local governments, and non-profit organizations	Put forward policy reform proposals to promote the construction of high-quality green buildings in Israel
Barari, S., et al.	green products	producers and retailers	An amalgam of α (the price elasticity of demand), β (marketing expenditure elasticity of demand), and the greening activities together determine the profits of a producing firm, and it breaks the myth that additional greening investments are void; rather they have the tendency to return back by influencing the market
Qian, Q.K., et al.	green building market	the stakeholders in the green building market	The main factor hindering the development was the high transaction cost
Chen, Q., et al.	prefabricated construction	the government and the construction industry	Two stakeholders' choices of strategy were dependent on the initial state and some key parameters of choices. Finally, both stakeholders achieve a win-win situation and make the construction industry can be sustainable development.

As for issues occurring in the development of prefabricated residential buildings, many scholars have proposed related elaboration. After collecting literature, many scholars think that incremental cost is the key factor affecting the development of prefabricated residential buildings. As costs in prefabricated residential buildings become the key factor affecting the development and application, many scholars analyze the costs and offer control measures accordingly. Some of scholars can analyze and evaluate the overall benefits in prefabricated residential buildings from a whole-society perspective. However, few scholars have analyzed the cost-effectiveness of participants without taking into the

effects of account assembly rate on incremental cost-effectiveness. However, in the context of a market economic system, before studying the root cause of promoting prefabricated residential buildings, efforts are needed in studying costs and benefits of all participants involved in prefabricated residential buildings. Therefore, cost apportionments ratios are introduced in the article to analyze cost apportionments ratio of incremental cost in prefabricated residential buildings through game theory. In doing so, studies can be conducted on economical efficiency of prefabricated residential buildings and incremental costs of the real estate development enterprise, which can be alleviated by policies.

Scholars applied evolutionary game to the construction industry, especially to green buildings, low-carbon buildings, prefabricated buildings, and other buildings with economic externality. Both governments and real estate development enterprise can have a great impact on prefabricated buildings. Owing to different levels of rights and interests, these two sides have different needs for interests. It is necessary for us to avoid development obstacles produced by interest conflicts. Then interest equilibrium can be found by means of game so as to balance the relationship between incremental cost and incremental benefit. Finally, these efforts can jointly contribute to promoting the development mechanism of prefabricated residential buildings.

3. Construction of the Evolutionary Game Model between the Government and the Real Estate Enterprises

3.1. Foundations of Evolutionary Game Theory

Evolutionary game theory, which is based on biological evolution theory and genetic theory, assumes that the participating subjects are finitely rational, which is more in line with the actual situation [23]. The traditional game theory focuses on the study of game equilibrium but ignores the process of achieving equilibrium. Evolutionary game theory analyzes groups from a dynamic perspective; the subject continuously corrects its own behavior by imitating successful strategies. It is possible to characterize the evolutionary trend of choosing a certain strategy within the group by simulating dynamic equations [24]. In evolutionary game theory, the government will develop appropriate incentive policies to guide the market in the early stages of industry development and then regulate the market once it has stabilized. Real estate developers will take a wait-and-see attitude when the industry is not well developed but will enter the market when it is well developed and choose the assembly model. Similarly, for consumers, if the purchase price of prefabricated residential products is too high and the benefits are not obvious, they will choose traditional construction products. On the contrary, when the market develops to a reasonable price, they will also choose to buy prefabricated residential ones [25]. Therefore, the basic theory and analysis methods of the evolutionary game theory have good feasibility and applicability to portray the behavior of the stakeholders in the application process of prefabricated residential buildings. On the one hand, in the construction industry, there are many stakeholders. The conditions of the same type of stakeholders are also different. The same type of stakeholders will form a group, and it is more objective and comprehensive when the game analysis is carried out based on groups. On the other, due to the continuous changes in the market, it is impossible that prefabricated residential buildings can occupy most of the market in a short period of time. The result of system evolution, which is formed by the main stakeholders through continuous learning and imitation, is a long-term dynamic process, and the evolutionary path can also be portrayed by analyzing the utility of the stakeholders and constructing a replication dynamic equation. Therefore, it is reasonable and applicable to use the evolutionary game method to analyze the game of major stakeholders and study the evolution process when applying prefabricated residential buildings in the market.

Based on the above analysis, it can be concluded that the stakeholders in the development process of prefabricated residential buildings are the government, real estate enterprises, and consumers. The interaction mechanism between them is shown in Figure 1.

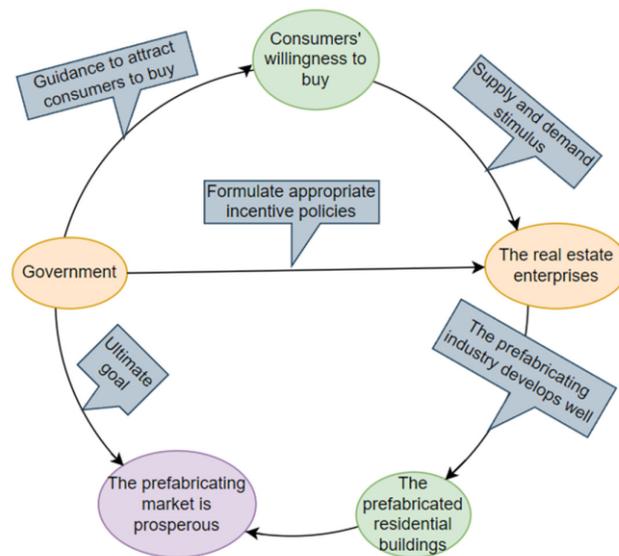


Figure 1. Mechanism between the government and real estate enterprises.

3.2. Model Hypothesis

Firstly, before constructing an evolutionary game model where information is asymmetric, the following assumptions are given:

Hypothesis 1: This study focuses on the trade-offs between the government and the real estate developers in the game of decision making for the development of developing prefabricated residential projects. Therefore, the willingness to buy (denoted by W) is chosen as an important variable in measuring the benefits of the government's and real estate developers' decisions. Only when a real estate enterprise chooses prefabricating model in its project can the consumer's willingness to buy affect the calculation of profit and loss of both parties [26]. In addition, the consumers mentioned in this paper are those who must buy an apartment, and there are only two options: standard residence and prefabricated residence.

Hypothesis 2: In the background that the government is promoting prefabricated residential buildings, the government will definitely incentivize companies to construct them, only that incentive measures are different. Implementing economic incentive policies means providing subsidies to real estate enterprises, the form of policies is various, and it is easy to land and attract them. Formal incentive policies are mainly based on initiatives and incentives without subsidies. The government strategy sets are {Economic incentives, spiritual incentives}. For real estate enterprises, the drive for interest means that they will definitely construct new projects, only that the forms of projects are different. So, the strategy sets of real estate enterprises are set as {Develop prefabricated houses and develop traditional houses}. Encouraged by the government's economic incentives, real estate enterprises construct prefabricated houses at the cost of incremental costs, thereby obtaining incremental economic benefits and government subsidies. In turn, it helps to obtain environmental and social benefits for the government to reduce pollution control costs and social governance costs [27].

Hypothesis 3: The probability of the government choosing a behavioral strategy for economic incentives is x , and the probability of choosing spiritual motivation is $1 - x$; The probability that a real estate enterprise chooses to develop prefabricated residential buildings is y , the probability of choosing to develop traditional building is $1 - y$, $x, y \in [0, 1]$, both as a function of time t .

Hypothesis 4: Both the government and real estate enterprises have two strategies and they can only choose one strategy at a time. The government and real estate enterprises adopt strategies independently and change strategies dynamically. The only criterion for making decisions is to maximize profits. However, their priorities are different. Real estate enterprises focus on maximizing

economic profits, while the government puts social interests first, as protecting the safety of citizens is an important part of its responsibility. Moreover, both parties are finite rational subjects, and the two play games repeatedly to look for the optimal strategy as information is asymmetric.

3.3. Profit and Loss Variables of Each Participant

Assumptions are made about the relevant parameters of the game between the government and real estate enterprises; the specific meanings are as shown in the Table 2.

Table 2. Variable parameters of profit and loss for government and real estate enterprises.

Parameter Symbol	Meaning of Parameter
E_1	Benefits for real estate enterprises constructing traditional residential housing
C_1	Costs for real estate enterprises constructing traditional residential housing
ΔE	Incremental benefits from constructing prefabricated residential buildings, and $\Delta E_1 = \eta(k)$, $\eta(k)$ are the increasing function of prefabrication rate k , $\eta(0) = 0$
ΔC	Incremental costs from constructing prefabricated residential buildings, and $\Delta C_1 = \varphi(k)$, $\varphi(k)$ are the increasing function of prefabrication rate k , $\varphi(0) = 0$
E_2	Benefits for government constructing traditional residential housing
C_2	The cost of the government for increasing its promotion efforts in order to promote the development of the prefabricated residential market
C_3	Environmental improvement costs invested by the government when constructing traditional residential buildings
L_1	Losses to the local economy due to consumers' scruples about prefabricated residential buildings
a	The incremental benefit distribution coefficient of the government constructing prefabricated residential buildings, and the economic incentive status is a_1 , the mental incentive status is a_2 , $0 \leq a \leq 1$
b	On condition that the economic incentive is in place, the incremental cost-sharing coefficient of the government for developing prefabricated residential buildings, $0 \leq b \leq 1$
P_1	On condition that the economic incentive is in place, the additional fines paid by real estate enterprises when prefabricated houses do not meet the expected prefabrication rate or other relevant regulations
L_2	Loss of sales due to consumers' scruples about prefabricated homes
k	Prefabrication rate of prefabricated houses, the economic incentive status is k_1 , the mental incentive status is k_2 , $0 \leq k_2 \leq k_1 \leq 1$

3.4. Model Building

Based on the above basic assumptions, 2×2 asymmetric evolution game model is constructed, and the revenue matrix is shown in Table 3.

Table 3. Revenue matrix of government and real estate enterprises.

Government	Real Estate Enterprises	
	Construction of Prefabricated Residential Buildings (y)	Construction of Traditional Housing ($1 - y$)
Economic incentives (x)	$W * (E_2 + \eta(k_1) * a_1 - C_2 - \varphi(k_1) * b) + (1 - W) * (E_2 + \eta(k_1) * a_1 - C_2 - \varphi(k_1) * b - L_1)$ $W * (E_1 + \eta(k_1) * (1 - a_1) - C_1 - \varphi(k_1) * (1 - b)) + (1 - W) * (E_1 + \eta(k_1) * (1 - a_1) - C_1 - \varphi(k_1) * (1 - b) - L_2)$	$E_2 + P_1 - C_2 - C_3$ $E_1 - P_1 - C_1$
Mental incentives ($1 - x$)	$W * (E_2 + \eta(k_2) * a_2 - C_2) + (1 - W) * (E_2 + \eta(k_2) * a_2 - C_2 - L_1)$ $W * (E_1 + \eta(k_2) * (1 - a_2) - C_1 - \varphi(k_2)) + (1 - W) * (E_1 + \eta(k_2) * (1 - a_2) - C_1 - \varphi(k_2) - L_2)$	$E_2 - C_2 - C_3$ $E_1 - C_1$

3.5. Model Analysis

3.5.1. Stability Analysis of the Government's Unilateral Strategy

As shown in the table above, if the government adopts economic incentive policies and real estate enterprises respond to incentive, the expected gain to the government (U_{x1}) can be measured by Equation (1).

$$U_{x1} = y * [W * (E_2 + \eta(k_1) * a_1 - C_2 - \varphi(k_1) * b) + (1 - W) * (E_2 + \eta(k_1) * a_1 - C_2 - \varphi(k_1) * b - L_1)] \quad (1)$$

If real estate enterprises do not respond to the government's economic incentives, the expected benefits (U_{x2}) for government should be:

$$U_{x2} = (1 - y) * (E_2 + P_1 - C_2 - C_3) \quad (2)$$

Therefore, when the government adopts economic incentive policies (U_x), the expected earnings are as follows:

$$U_x = U_{x1} + U_{x2} = y * [W * (E_2 + \eta(k_1) * a_1 - C_2 - \varphi(k_1) * b) + (1 - W) * (E_2 + \eta(k_1) * a_1 - C_2 - \varphi(k_1) * b - L_1)] + (1 - y) * (E_2 + P_1 - C_2 - C_3) \quad (3)$$

Similarly, when the government adopts mental incentive policies (U_{1-x}), the expected earnings are as follows:

$$U_{1-x} = y * [W * (E_2 + \eta(k_2) * a_2 - C_2) + (1 - W) * (E_2 + \eta(k_2) * a_2 - C_2 - L_1)] + (1 - y) * (E_2 - C_2 - C_3) \quad (4)$$

Therefore, the average expected benefits of the government is:

$$U_g = x * U_x + (1 - x) * U_{1-x} \quad (5)$$

Based on the calculation method of evolutionary game theory, the replicator dynamics equation of government is expressed as $F(x)$ [28], then

$$F(x) = x(U_x - U_g) = x(1 - x)(U_x - U_{1-x}) = x(1 - x)[y(\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b - P_1) + P_1] \quad (6)$$

If $y^* = \frac{-P_1}{\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b - P_1}$ (make $\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b = A$), then any choice of x , the result is always $F(x) = 0$, indicating that all x are in a stable state, that is to say, when the probability of real estate enterprises developing prefabricated residential buildings reaches $y^* = \frac{-P_1}{\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b - P_1}$, no matter whether the government implements economic incentives or mental incentives, the benefits obtained by the government will not change.

If $y^* \neq \frac{-P_1}{\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b - P_1}$, and let $F(x) = 0$, two possible stabilization points can be obtained with $x^* = 0$ and $x^* = 1$ two possible stability points.

The derivative of $F(x)$ gives:

$$\frac{\partial F(x)}{\partial x} = (1 - 2x) [y(\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b - P_1) + P_1] \quad (7)$$

According to the theorem, only when $F'(x) > 0$ are satisfied can the evolutionary stability strategy be satisfied, so the different situations should be discussed.

(1) when $A > 0$, $y^* < 0$ or $y^* > 1$, at this time $F'(0) > 0$, $F'(1) < 0$, $x = 1$ are the only stable strategy.

(2) when $A < 0$, $y^* > 0$, at this time the discussion of value y is divided into two situations: a: when $0 < y^* < y$, $F'(0) < 0$, $F'(1) > 0$, $x = 0$ is the only stable strategy;

b: when $0 < y < y^*$, $F'(0) > 0$, $F'(1) < 0$, $x = 1$ is the only stable strategy.

3.5.2. Stability Analysis of Unilateral Strategies of Real Estate Enterprises

Similarly, the replication dynamic equation of real estate enterprises $F(y)$ is measured through the following equations.

$$U_y = x[W * (E_1 + \eta(k_1) * (1 - a_1) - C_1 - \varphi(k_1) * (1 - b)) + (1 - W) * (E_1 + \eta(k_1) * (1 - a_1) - C_1 - \varphi(k_1) * (1 - b) - L_2)] + (1 - x)[W * (E_1 + \eta(k_2) * (1 - a_2) - C_1 - \varphi(k_2)) + (1 - W) * (E_1 + \eta(k_2) * (1 - a_2) - C_1 - \varphi(k_2) - L_2)] \quad (8)$$

$$U_{1-y} = x(E_1 - P_1 - C_1) + (1 - x)(E_1 - C_1) \quad (9)$$

Therefore, the average expected return for real estate enterprises is

$$U_d = y * U_y + (1 - y) * U_{1-y} \quad (10)$$

Based on the calculation method of game theory, the replicator dynamics equation of real estate enterprises is expressed as $F(y)$, then

$$F(y) = y(U_y - U_d) = y(1 - y)(U_y - U_{1-y}) = y(1 - y)[x(\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1) - (\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W)] \quad (11)$$

If $x^* = \frac{\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W}{\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1}$ (make $\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1 = B$, $\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W = C$), then any y , the result is always $F(y) = 0$, indicating that all y are in a stable state, that is, when the probability of government economic incentives reaches, $x^* = \frac{\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W}{\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1}$, regardless of whether the real estate enterprise develops traditional residential or prefabricated residential buildings, the income obtained by the real estate enterprise will not change.

If $x^* \neq \frac{\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W}{\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1}$, make $F(y) = 0$, then there are $y^* = 0$ and $y^* = 1$ two possible stability points.

Finding the derivative of $F(y)$:

$$\frac{\partial F(y)}{\partial y} = (1 - 2y)[x(\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1) - (\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2)] \quad (12)$$

According to the theorem, only when $F'(y) < 0$ is satisfied can the evolutionary stability strategy be satisfied, so the different situations should be discussed.

- (1) when $B < C$ and $C > 0$, $x^* < 0$ or $x^* > 1$, at this time $F'(0) < 0$, $F'(1) > 0$, $y = 0$ is the only stable strategy.
- (2) when $B > C$ and $C < 0$, $x^* < 0$ or $x^* > 1$, at this time $F'(0) > 0$, $F'(1) < 0$, $y = 1$ is the only stable strategy.
- (3) when $B > C > 0$, $x^* > 0$, at this time the discussion of value x is divided into two situations:
 - a: when $0 < x^* < x$, $F'(0) > 0$, $F'(1) < 0$, $y = 1$ is the only stable strategy;
 - b: when $0 < x < x^*$, $F'(0) < 0$, $F'(1) > 0$, $y = 0$ is the only stable strategy.
- (4) when $B < C < 0$, $x^* > 0$, at this time the discussion of value x is divided into two situations:
 - a: when $0 < x^* < x$, $F'(0) < 0$, $F'(1) > 0$, $y = 0$ is the only stable strategy;
 - b: when $0 < x < x^*$, $F'(0) > 0$, $F'(1) < 0$, $y = 1$ is the only stable strategy.

3.5.3. Analysis on the Evolutionary Stability of the Hybrid Strategy of the Government and Real Estate Enterprises

According to Friedman [29], the stability of the equilibrium point of the evolutionary system can be determined by the Jacobi obtained from the system. In order to analyze the evolutionary game trend between the government and real estate enterprises, the Jacobi matrix is established [30], as shown in (13). Based on the matrix, we can get its determinant (Det_j) and trajectory (Tr_j) (see Equations (18) and (19)).

$$J(x, y) = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \tag{13}$$

$$\frac{\partial F(x)}{\partial x} = (1 - 2x)[y(\eta(k_1) * a_1 - \eta(k_1) * a_2 - \varphi(k_1) * b - P_1) + P_1] \tag{14}$$

$$\frac{\partial F(x)}{\partial y} = x(1 - x)(\eta(k_1) * a_1 - \eta(k_1) * a_2 - \varphi(k_1) * b - P_1) \tag{15}$$

$$\frac{\partial F(x)}{\partial x} = y(1 - y) (\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1) \tag{16}$$

$$\frac{\partial F(y)}{\partial y} = (1 - 2y) [x(\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(a_2) + P_1) - (\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W)] \tag{17}$$

$$Det_j = \frac{\partial F(x)}{\partial x} * \frac{\partial F(y)}{\partial y} - \frac{\partial F(x)}{\partial y} * \frac{\partial F(y)}{\partial x} = \{(1 - 2x)[y(\eta(k_1) * a_1 - \eta(k_1) * a_2 - \varphi(k_1) * b - P_1) + P_1] * \{(1 - 2y)[x(\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(a_2) + P_1) - (\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W)]\} - \{x(1 - x)(\eta(k_1) * a_1 - \eta(k_1) * a_2 - \varphi(k_1) * b - P_1)\} * \{y(1 - y) (\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1)\} \tag{18}$$

$$Tr_j = \frac{\partial F(x)}{\partial x} + \frac{\partial F(y)}{\partial y} = (1 - 2x)[(\eta(k_1) * a_1 - \eta(k_1) * a_2 - \varphi(k_1) * b - P_1) + P_1] + (1 - 2y)[x(\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(a_2) + P_1) - (\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W)] \tag{19}$$

According to the analysis method of local stability of the Jacobi matrix, it can be seen that when the equilibrium point satisfies the determinant $Det_j > 0$ and trace $Tr_j < 0$; it shows that the system is in a local gradual stable state during dynamic evolution. This point is regarded as the system’s local evolutionary stability strategy (ESS) [31]. According to the above equation, Det_j and Tr_j at each equilibrium point are as shown in Table 4.

Table 4. Adjustment and analysis table of equilibrium point’s stability.

Equilibrium Point	Det_j	Tr_j
(0,0)	$P_1 * \{\eta(k_2) * (1 - a_2) - \varphi(k_2) - L_2 + L_2W\}$	$P_1 + \eta(k_2) * (1 - a_2) - \varphi(k_2) - L_2 + L_2W$
(0,1)	$\{\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b\} * \{\varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W\} * (-P_1) *$	$\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b + \varphi(k_2) + L_2 - \eta(k_2) * (1 - a_2) - L_2W$
(1,0)	$\{\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) + P_1 - L_2 + L_2W\}$	$\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - L_2 + L_2W$
(1,1)	$\{\eta(k_2) * a_2 + \varphi(k_1) * b - \eta(k_1) * a_1\} * \{L_2 + \varphi(k_1) * (1 - b) - \eta(k_1) * (1 - a_1) - P_1 - L_2W\}$	$\eta(k_2) * a_2 + \varphi(k_1) - \eta(k_1) - P_1 + L_2 - L_2W$
(x^*, y^*)	$-\{x(1 - x)(\eta(k_1) * a_1 - \eta(k_2) * a_2 - \varphi(k_1) * b - P_1)\} * \{y(1 - y)(\eta(k_1) * (1 - a_1) - \varphi(k_1) * (1 - b) - \eta(k_2) * (1 - a_2) + \varphi(k_2) + P_1)\}$	0

According to the Jacobian matrix Det_j and Tr_j , an analysis of the local stability of the equilibrium points of the game system was made, as shown in the Table 5, only when $0 < x^* < 1$, $0 < y^* < 1$ there is a fifth equilibrium point, that is, the situation of (g), (h) in Table 5.

Table 5. Analysis of local stability of each equilibrium point.

Equilibrium Point	(0,0)	(0,1)	(1,0)	(1,1)	(x^*, y^*)
(a) $A > 0, B < C$ and $C > 0$					
Det_j/Tr_j Stability	$-/\pm$ Saddle point	$+/+$ Unstable	$+/-$ ESS	$-/\pm$ Saddle point	$-$ $-$
(b) $A > 0, B > C$ and $C < 0$					
Det_j/Tr_j Stability	$+/+$ Unstable	$-/\pm$ Saddle point	$-/\pm$ Saddle point	$+/-$ ESS	$-$ $-$
(c) $A > 0, B > C > 0$					
Det_j/Tr_j Stability	$-/\pm$ Saddle point	$+/+$ Unstable	$-/\pm$ Saddle point	$+/-$ ESS	$-$ $-$
(d) $A > 0, B < C < 0$					
Det_j/Tr_j Stability	$+/+$ Unstable	$-/\pm$ Saddle point	$+/-$ ESS	$-/\pm$ Saddle point	$-$ $-$
(e) $A < 0, B < C$ and $C > 0$					
Det_j/Tr_j Stability	$-/\pm$ Saddle point	$-/\pm$ Saddle point	$+/-$ ESS	$+/+$ Unstable	$-$ $-$
(f) $A < 0, B > C$ and $C < 0$					
Det_j/Tr_j Stability	$+/+$ Unstable	$+/-$ ESS	$-/\pm$ Saddle point	$-/\pm$ Saddle point	$-$ $-$
(g) $A < 0, B > C > 0$					
Det_j/Tr_j Stability	$-/\pm$ Saddle point	$-/\pm$ Saddle point	$-/\pm$ Saddle point	$-/\pm$ Saddle point	$-/0$ Saddle point
(h) $A < 0, B < C < 0$					
Det_j/Tr_j Stability	$+/+$ Unstable	$+/-$ ESS	$+/-$ ESS	$+/+$ Unstable	$+/0$ Saddle point

3.6. Result Analysis

Based on the above analysis, it is possible to draw the evolution process of the game between the government and the real estate enterprises under different circumstances, as shown in Figure 2 and (a)–(h) in Figure 2 correspond to the eight circumstances of (a)–(h) in Table 5, respectively.

Based on the above model analysis, the following conclusions are drawn:

(1): In Figure 2, the circumstances in (a) and (d) all converge to (1,0), the system finally converges to (economic incentives, development of traditional housing), that is to say, real estate enterprises do not construct prefabricated residential buildings. In this case, since the green awareness of the government is improving, it is also willing to bear the additional construction costs of prefabricated residential buildings. However, since real estate enterprises cannot realize excess returns in the process of constructing prefabricated residential buildings, their intention of constructing such buildings is low. Consequently, they would still prefer traditional buildings.

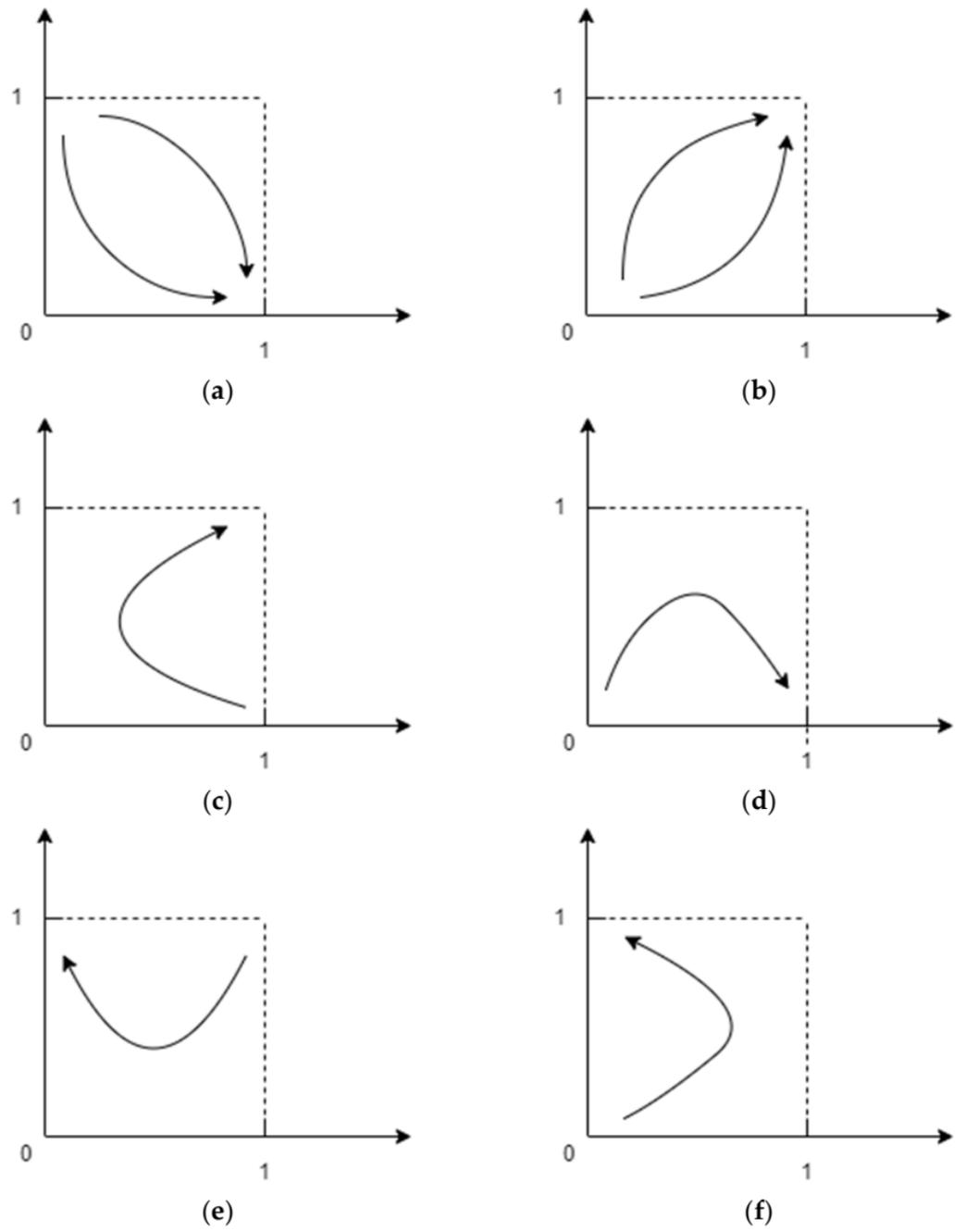


Figure 2. Cont.

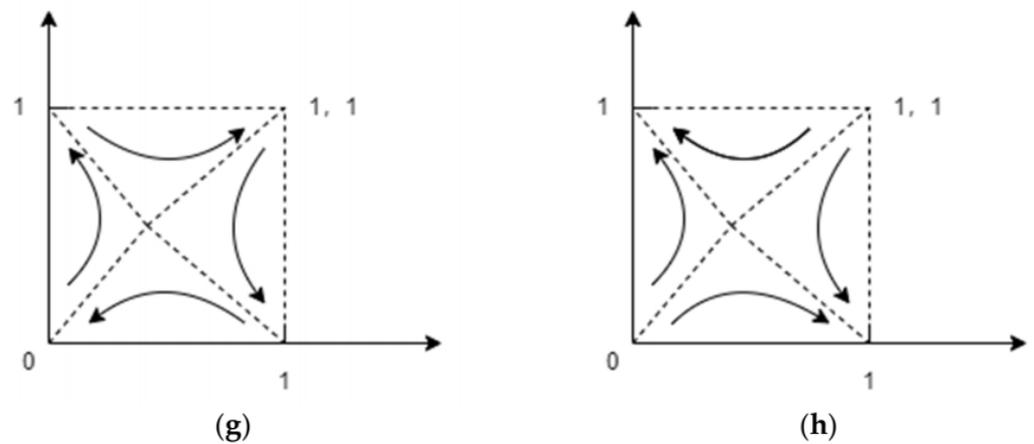


Figure 2. Phase diagram of the evolution of system under different circumstances.

(2): The circumstances in (e) and (f) all converge to (0,1), the system finally converges to (mental incentive, development of prefabricated residential buildings), that is to say, real estate enterprises choose to construct prefabricated residential buildings. As more and more real estate enterprises are constructing prefabricated buildings, prefabricated residential building development has reached a certain scale. At this time, to reduce financial pressure and gain greater revenue, the government will gradually reduce its support or incentive policies for prefabricated buildings; the market condition is not positive.

(3): The circumstances in (b) and (c) all converge to (1,1), that is to say, the system finally converges to (economic incentives, development of prefabricated residential buildings). This is an ideal state. At this time, driven by green benefits, the government will vigorously support real estate enterprises, while real estate enterprises will take the initiative to construct prefabricated residential buildings. This means that economic incentives and the development of prefabricated residential buildings have become the best choices for both the government and real estate development enterprises.

(4): In circumstance (g), there is no stable strategy, and the result of the game may develop in any one direction of the four strategy combinations.

(5): In circumstance (f), it is possible to converge to (0,1) or (1,0); the conclusion (1) and (2) can be referred to at this time.

4. Application of Evolutionary Game Model between Government and Real Estate Enterprises

4.1. Project Overview

Project A by Cheng Xiang Construction Company of Heilongjiang Province is a representative prefabricated residential project in Wuhan. Hence, it was selected as a reference for calculating the initial values of these variables. The project takes up to 391,000 square meters, with a floor area ratio of 3.4. Building #11 adopted prefabricated construction, and the prefabrication rate is 56.2%; the exterior walls, floors, stairs, balconies, air-conditioning panels, and decorative panels were prefabricated. Since it was a representative project by the government that was used to compare and analyze the economic, technical, and environmental impacts, it was rather easy to acquire detailed construction information and precise data. The main project information of this project is shown in Table 6 and incremental cost increase under different assembly rates is shown in Table 7. The cast-in-place and prefabricating design were provided by the local architectural design institute, and data was acquired through on-site research and interviews with construction technicians.

Table 6. Main information of the project.

Serial Number	Name of Indicator	Traditional Cast-in-Place Residential Building (#8)	Prefabricated Residential Building (#11)
1	Gross floor area	21,722	21,722
2	Building type	Cast-in-place shear wall structure	Integral prefabrication and assembly Shear wall structure
3	Construction method	Cast-in-place	Prefabricated assembly + Cast-in-place
4	Floor area ratio	3.4	3.4
5	Price (yuan/m ²)	11,300	11,800
6	Construction cost (yuan/m ²)	9300	9700

Table 7. Incremental cost increase under different assembly rates.

Project	Architectural Nature	Structure	Assembly Rate/%	Cost Increase/%
1	residential	Shear wall	10	11.87
2	residential	Shear wall	10	17
3	residential	Shear wall	10	19.17
4	residential	Shear wall	10.71	24
5	residential	Shear wall	15	29
6	residential	Shear wall	20	36.17
7	residential	Shear wall	30	37.5
8	residential	Shear wall	50	41.7
9	residential	Shear wall	65	68.84
10	residential	Shear wall	70	57.74
11	residential	Shear wall	75.5	40.32

According to the fitting results of Origin, the relationship between incremental cost increase of prefabricated shear wall structure (y) and assembly rate (x) can be expressed as: $y = -61.62x^5 + 66.62x^4 + 3.22x^3 - 22.78x^2 + 7.74x - 0.38$ (among which $R^2 = 0.94$). The fitting curve of assembly rate and incremental cost increase is shown in Figure 3.

From Figure 3, it can be seen that when the assembly rate of assembled shear wall is in the range of 10–20%, the curve has an obvious upward trend, and the slope is large, which indicates that the cost of the assembled shear wall has increased, and the incremental cost will increase as the assembly rate increases and a large increase happens accordingly; when the assembly rate is between 20 and 45%, the curve is rather horizontal, which indicates that the cost increase of assembled shear wall is relatively stable. If the building assembly rate is between 45 and approximately 65%, the curve will increase again, and when it reaches 65%, the increased value of the cost increment of construction projects has reached its peak.

Based on the above data, the values of the relevant parameters can be roughly estimated as shown in Table 8:

Table 8. Initial and new values of all variables.

Variable	Initial Value	New Value	Variable	Initial Value	New Value
ΔE_1	3	9	a_2	0.1	0.1
ΔE_2	1	5	b	0.4	1
ΔC_1	6	1	P_1	0.5	2.4
ΔC_2	3	0.5	L_2	1.5	0.3
a_1	0.5	0.5	W	0.4	0.7

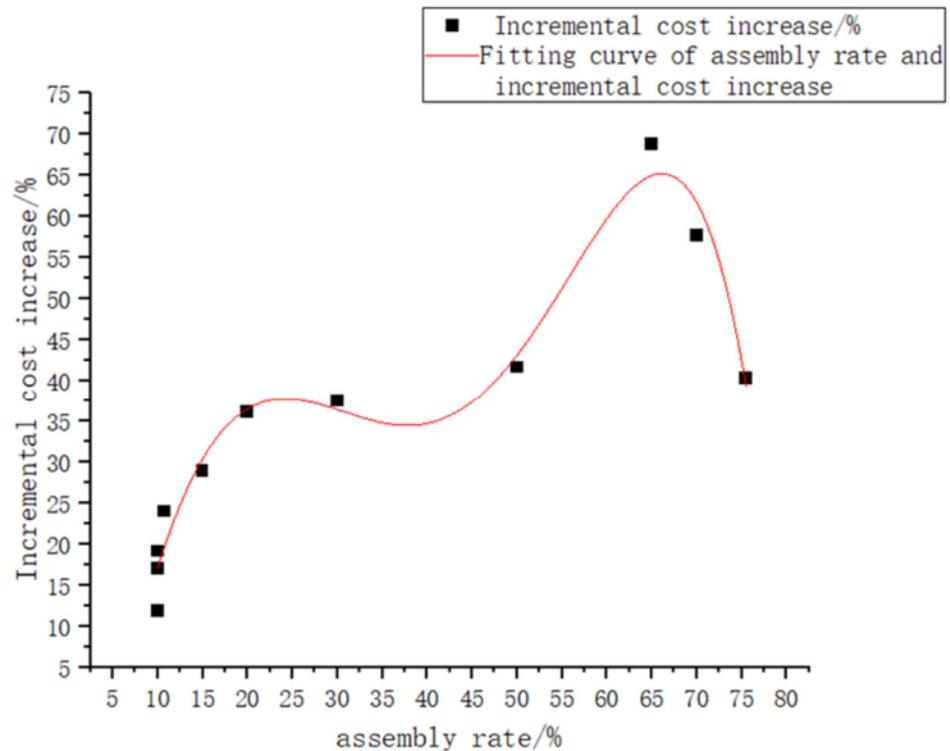


Figure 3. Assembly rate curve of incremental cost increase.

Using Matlab software to simulate results, the above variables and the replicator dynamics (Equations (7) and (12)) are input to Matlab2016a. Simulation diagrams of some key variables are obtained, as shown in the figure. In these numbers, axis y represents the probability of the government adopting incentive policies (x) or the probability of a real estate enterprise implementing prefabricated residential buildings in its project (y). The axis x represents the evolutionary process. Affected by the initial allocated value, the marked lines x1 and y1 reflect the evolution trend of the government and real estate enterprises, respectively. The simulation of new value (1) is represented and marked by x2 and y2.

4.2. Influence on Evolutionary Behavior of Changes of Different Parameters

(1). Influence on evolutionary game of incremental cost-effectiveness ΔE , ΔC

It can be seen from Figures 4 and 5 that the incremental cost of prefabricated residential projects is obvious now, and the incremental benefits are obviously under perceived. Reducing incremental costs or increasing incremental benefits has little impact on the game strategy. Real estate enterprises will tend to choose to construct prefabricated residential projects only when the incremental benefits are significantly greater than the incremental costs. Only in this way may the evolution of game develop in a good direction.

(2). Influence on evolutionary game of incremental cost sharing factor b

From the simulation results shown in Figure 6, it can be seen that the increase of the government's cost-sharing coefficient for real estate enterprises to develop prefabricated residential buildings is not conducive to the right development {Develop prefabricated residential buildings and incentives} of the game. Hence, it is not conducive to developing the prefabricated residential market. Therefore, it cannot change the development dilemma of the prefabricated residential buildings market if the government simply increases its economic subsidies to enterprises. Investing limited government funds in technology and policy promotion may be a better way to promote prefabricated residential buildings [32].

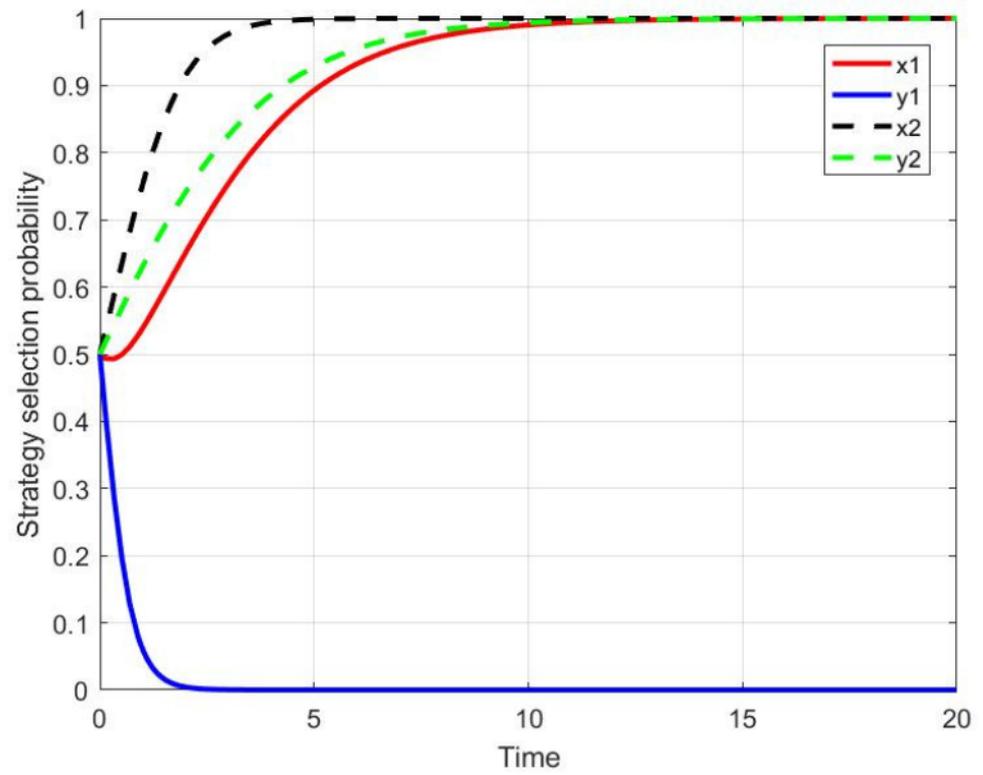


Figure 4. The influence of incremental benefits on evolutionary game.

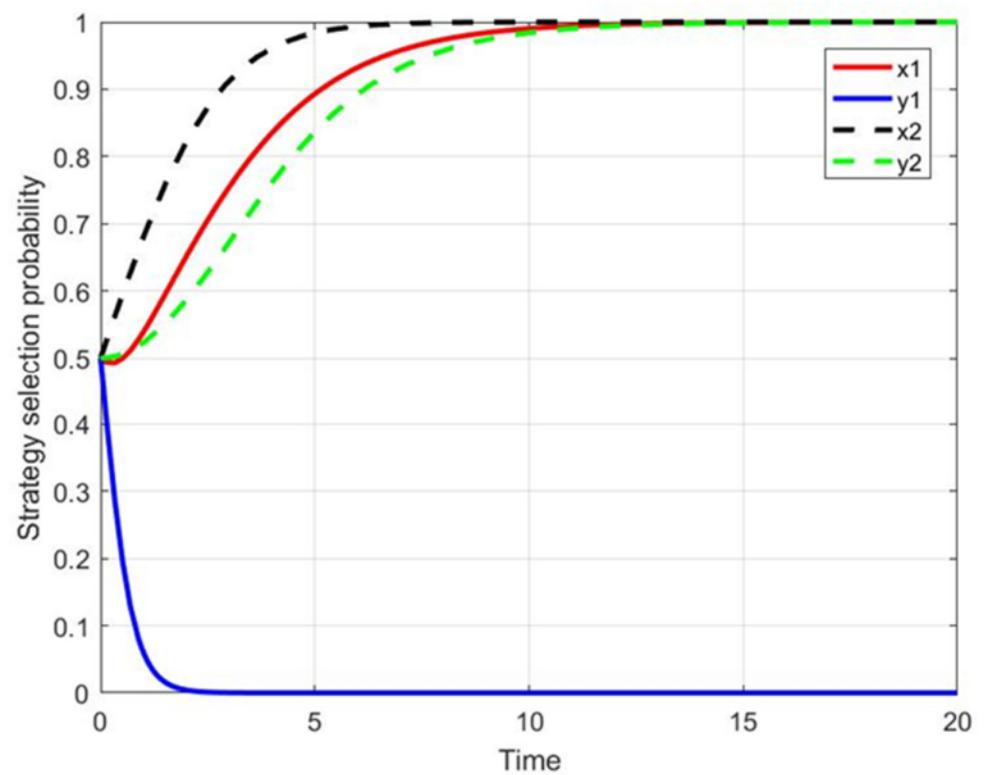


Figure 5. The influence of incremental cost on evolutionary game.

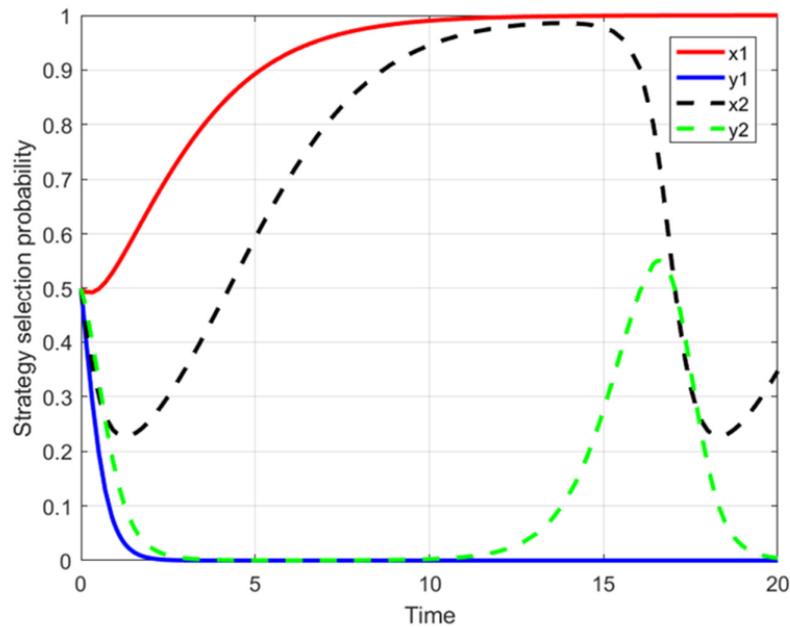


Figure 6. The influence of incremental cost-sharing coefficient on evolutionary game.

- (3). Influence on the evolutionary game of additional fines paid P_1 , loss of sales L_2 , and consumers' willingness to buy W .

From Figure 7, it can be seen that compared to the government's direct allocation of incremental costs, real estate enterprises are more sensitive to negative incentive policies. By increasing penalties on real estate enterprises that have not responded positively, it can promote the development strategies of both parties to achieve equilibrium faster. Therefore, in the incentive policy system, positive and negative incentives should be rationally combined with each other to maximize the effectiveness of incentives [1].

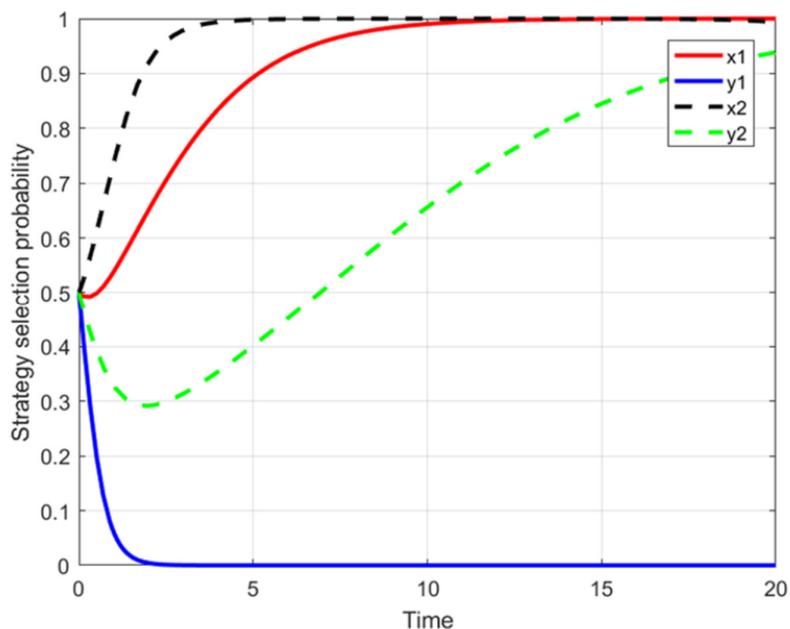


Figure 7. Influence on the evolutionary game of additional fines paid, loss of sales and consumers' willingness to buy.

In the short term, consumers' willingness to buy has no impact on the strategic choices of real estate enterprises. When consumers' willingness W reaches 1, and loss of sales L_2 is 0, the game evolves towards an ideal state. It is assumed in this paper that the sales price of prefabricated houses is different from that of traditional buildings. The increase in consumers' willingness to buy can reduce the sales' losses of real estate enterprises and generate additional sales profits. In this case, real estate enterprises tend to choose prefabricated houses.

5. Discussion and Policy Suggestions

5.1. Discussion on the Current Situation

(1): It is an effective way to reduce the incremental cost of real estate enterprises with the government sharing the incremental cost of prefabricated residential buildings, and it directly encourages real estate enterprises for the construction. However, the increase in government subsidies will increase the financial burden. On the other hand, subsidies cannot solve the key problem of the incremental cost of prefabricated residential buildings, which is not conducive to guiding the prefabricated residential buildings industry to achieve sustainable development by reducing costs through self-innovation.

(2): When encouraging constructing prefabricated building, introducing and improving supervision and punishment mechanisms will make the government guidance more effective. It is conducive to the healthy development of the industry. Moderate penalties for dust, noise, and non-compliance with pollution standards when constructing traditional residential buildings will make the real estate enterprises more willing to adopt prefabrication.

(3): Only when the incremental benefits of developing prefabricated residential buildings are greater than the incremental costs will real estate enterprises choose to develop prefabricated residential buildings. Increasing consumers' willingness to purchase such apartments moderately cannot greatly stimulate the market. The incremental benefits of prefabricated residential buildings compared to the traditional ones are the key to whether real estate enterprises want to construct prefabricated buildings. As an important participant in the prefabricated residential market, consumers' influence has not been taken seriously. The sustainable development of the prefabricated residential industry relies on the growth of both supply and demand. Hence, the government's incentive policies should not only focus on the supply side but also on the demand side. Effective publicity and incentives should be carried out to enhance consumers' willingness to buy prefabricated residential buildings.

(4): There is a positive correlation between the incremental cost and the assembly rate of prefabricated residential buildings. Different assembly rates have different incremental costs. The government can provide certain financial subsidies based on the assembly rate. In this way, the incremental cost of prefabricated residential properties for real estate enterprises can be reduced while ensuring the assembly rate.

5.2. Policy Suggestions

Based on the above conclusions, the following suggestions are provided for improving the incentive policy of prefabricated residential buildings:

(1): Improve incremental cost control by means of technological innovation. Unlike traditional buildings, prefabricated residential buildings will use multiple technical indicators during construction, and different high-tech content indicators can promote the transformation and upgrading of prefabricated buildings. If the government adopts measures such as cost-sharing to control incremental costs, it will even hinder the development of the entire industry. It is not hard to discover from studying a large number of building energy-saving data from the housing and construction sector and the integrated information management platform for prefabricated buildings that the number of buildings using high-tech rate in China is low. The major reason is that currently, the innovation of China's prefabricated houses is not enough, while the incremental cost of prefabricated

houses is relatively high. Therefore, the current market is too saturated, and real estate enterprises dare not to construct and develop prefabricated residential buildings on a large scale. Therefore, if we want to promote the long-term development of China's prefabricated residential buildings, we should stimulate scientific and technological innovation based on technical indicators. In 2017, China stipulated GB /T51129-2017 "Evaluation Criteria for Prefabricated Buildings", and GB /T51129-2015 "Evaluation Criteria for Industrial Buildings" was abolished at the same time. In the new standard, assembly rate was determined as a key indicator, and various measures were taken to develop key technical products for building energy conservation and prefabricated buildings. The aim is to promote building energy conservation and prefabricated residential buildings and to let building energy conservation develop concurrently with prefabricated residential buildings. To create a good environment for developing prefabricated residential buildings, it is necessary to adopt scientific and technological innovation methods and control incremental costs reasonably. The adaption of high-tech indicators should be controlled within a reasonable range.

(2): Set the incremental cost sharing coefficient reasonably. The value of the government's incremental cost-sharing coefficient affects the probability of developers applying prefabricated residential buildings directly. Therefore, it is very important for the government to set the value in the right way. It must be reasonable and perfect. The value should not be increased or set too low blindly. On the one hand, if the coefficient is too high, the incremental cost of real estate enterprises can be reduced sharply, and they can obtain greater benefits from prefabricated residential buildings; such strong incentives will encourage them to construct such buildings extensively. However, this effect is only short-term. It is merely because of the excessively high subsidy amount that such construction is attractive. The high cost borne by the government will inevitably bring pressure and restrict other government activities. As a result, these stimulus measures cannot be implemented for a long time. On the contrary, it reduces the government's willingness to promote prefabrication. This means that after increasing the value of the cost-sharing coefficient, the probability of real estate enterprises applying prefabricated residential buildings increases, but the time duration is not long. On the other hand, if the government sets the value too low, the subsidy effect will be too small. Therefore, it is necessary to adjust the value to a reasonable level. To encourage the development of prefabricated residential buildings, the government should make timely adjustments in response to market changes. In the meantime, it is easier to ensure the incentive strategy is stable and sustainable. In addition to direct economic compensation, diversified incentive strategies can also be adopted, such as monetary compensation per unit area, floor area ratio incentives, tax incentives, and enhanced credit.

(3): Combine positive and negative incentives together and promote actively. Among negative incentives, it can be seen from the conclusion that punishment is a very effective one. Reasonable design will rather greatly encourage the construction. Therefore, when encouraging prefabricated residential buildings, the government can implement certain punitive measures such as paying a certain percentage of penalty or forbidding land bidding within two years. Such punishment may be implemented if the real estate enterprises have not followed the government's economic incentive policies and still develop residential buildings in the traditional way or only respond to the policy superficially by taking advantage of the loopholes of policies, such as the prefabricated components being all non-structural components like stair slabs and balcony slabs. However, how strong the punishment is also needs to be controlled reasonably. After all, penalties are a means of punishment, which is for warning and supervision. Punishment cannot be used as the main means to encourage prefabricated residential buildings. If the punishment is set too high, the intervention will be too strong, which will not encourage the healthy development of prefabricated residential buildings. The government can also adopt multiple means when improving its punishment measures, such as publicizing the enterprises that create graver pollution, tightening approvals, and making land policies stricter, so as to form a dynamic and effective disciplinary mechanism. By analyzing loss of sales L_2 and consumers'

willingness to buy W , it can be seen that the consumers' willingness to buy can be improved by the government if it promotes prefabricated building actively. Like other commodities, market demand is one of the core factors in industry development [33]. In the construction industry, market demand is also crucial. If there is demand for prefabricated residential buildings, its promotion in the market will naturally go smoothly. To transform the public's impression of prefabricated residential buildings, the government can increase its promotion. When the public has started to know its advantages and benefits, they will purchase prefabricated residential buildings voluntarily. In turn, this will increase the market share.

(4): Set reasonable development goals. Both real estate enterprises and the government should set reasonable development goals based on the actual market conditions. The development of prefabricated residential buildings is gradual. We cannot seek high standards blindly. According to the evolutionary game and simulation between the government and real estate enterprises, it can be seen that when the government's support is insufficient to make up for the incremental cost of real estate enterprises, the higher the assembly rate, the higher the incremental cost. Real estate enterprises should reduce some assembly rates regarding their own economic conditions, and to a certain extent, reducing the incremental cost will help the game to develop to an ideal state. Jaillon pointed out that in Hongkong, China, private prefabricated buildings were market-oriented and commercialized, and normally the assembly rate was lower than 15%. However, for projects lead by the government, the assembly rate usually reached over 40%. Hence, the assembly rate for prefabricated residential buildings in China at present should not be set too high, and the rate can be increased appropriately for the state-led public housing construction projects.

6. Conclusions

In this paper, an analysis of the contradictions of prefabricated residential buildings is made from the perspective of incremental cost-benefit. Its benefits serve the entire society, but its costs are borne by the developers alone. In this case, with the goal of maximizing their own interests, real estate enterprises will naturally choose traditional construction methods that have higher benefits for them. To promote prefabricated residential buildings, it is necessary to improve incentive policies and make them more scientific and effective. Therefore, when analyzing the evolutionary game of prefabricated residential buildings from the perspective of cost-benefit that each stakeholder is concerned about, the value of the incremental cost-sharing coefficient is introduced to analyze the conflicts, and the impact of different assembly rates on incremental costs is introduced when studying incentive policies. The government can provide certain financial subsidies according to the assembly rate. The evaluation of prefabricated residential buildings can make it clear to specify some detailed requirements including low assembly rate and prefabricated type. As for some so-called prefabricated residential buildings, prefabrication is made in non-structural parts. The structure of the building is still cast-in-place construction. Furthermore, these buildings with very low assembly rate are not regarded as prefabricated buildings by the government. This paper believes that government should play a leading role in the initial stage of prefabricated residential buildings based on the long-term benefits brought by prefabricated residential buildings including resources, environment, and society. Some material incentive and policy support should be given to real estate development enterprise and consumers. After reducing incremental cost while increasing benefits in psychology and function of real estate development enterprises based on ensuring optimal assembly rate, we can better promote the development of prefabricated residential buildings. Finally, the sustainable development of the construction industry can be realized. As prefabricated residential buildings stand in the initial stage, the study on them is deepening. The article explores the incremental costs and incentive policies of prefabricated residential buildings. In view of the short time and limitations on the depth of research and sample data, further efforts are needed to strengthen the data collection work in the research. This is what the article will focus on in the next step. The focus of the research is on evolution

among government, the real estate development enterprise, and consumers. Because of the complex relationship among these three participants in prefabricated residential buildings, in-depth research is needed in the coming years. Despite the limitations, this study gives some very useful proposals for government based on the simulation results so as to ensure the efficiency of incentive policies in promoting the implementation of prefabricated residential buildings.

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References

1. Luo, T.; Xue, X.; Wang, Y.; Xue, W.; Tan, Y. A systematic overview of prefabricated construction policies in China. *J. Clean. Prod.* **2021**, *280*, 124371. [[CrossRef](#)]
2. Arif, M.; Egbu, C. Making a case for offsite construction in China. *Eng. Constr. Archit. Manag.* **2010**, *17*. [[CrossRef](#)]
3. Zhai, X.; Reed, R.; Mills, A. Factors impeding the offsite production of housing construction in China: An investigation of current practice. *Constr. Manag. Econ.* **2014**, *32*, 40–52. [[CrossRef](#)]
4. Wang, Y.; Li, H.; Wu, Z. Attitude of the Chinese public toward off-site construction: A text mining study. *J. Clean. Prod.* **2019**, *238*, 117926. [[CrossRef](#)]
5. Olawumi, T.O.; Chan, D.W.M. Concomitant impediments to the implementation of smart sustainable practices in the built environment. *Sustain. Prod. Consump.* **2020**, *21*, 239–251. [[CrossRef](#)]
6. Odugu, H.; Achuthan, A. Impact of prefabrication technology on profitability using Primavera p6. *Mater. Today* **2020**, *33*, 345–352. [[CrossRef](#)]
7. Gao, Y.; Tian, X.L. Prefabrication policies and the performance of construction industry in China. *J. Clean. Prod.* **2020**, *253*, 120042. [[CrossRef](#)]
8. Lovell, H.; Smith, S.J. Agencement in housing markets: The case of the UK construction industry. *Geoforum* **2010**, *41*, 457–468. [[CrossRef](#)]
9. Barriga, E.M.; Jeong, J.G.; Hastak, M.; Hastak, M.; Syal, M. Material control system for the manufactured housing industry. *J. Manag. Eng.* **2005**, *21*, 91–98. [[CrossRef](#)]
10. Yashiro, T. Conceptual framework of the evolution and transformation of the idea of the industrialization of building in Japan. *Constr. Manag. Econ.* **2014**, *32*, 16–39. [[CrossRef](#)]
11. Chiang, Y.H.; Chan, E.H.W.; Lok, L.K.L. Prefabrication and barriers to entry—A case study of public housing and institutional buildings in Hong Kong. *Habitat Int.* **2006**, *30*, 482–499. [[CrossRef](#)]
12. Hjort, B.; Lindgren, J.; Larsson, B.; Emmitt, S. Success factors related to industrialized building in Sweden. In Proceedings of the International Conference on Construction in a Changing World, Dambulla, Sri Lanka, 4–7 May 2014.
13. Cansino, J.M.; Pablo-Romero, M.D.; Román, R.; Yñiguez, R. Tax incentives to promote green electricity: An overview of EU-27 countries. *Energy Policy* **2010**, *38*, 6000–6008. [[CrossRef](#)]
14. Rosas, A. Evolutionary game theory meets social science: Is there a unifying rule for human cooperation? *J. Theor. Biol.* **2010**, *264*, 450–456. [[CrossRef](#)]
15. Potochnik, A. Modeling social and evolutionary games. *Stud. Hist. Philos. Sci. Part C* **2012**, *43*, 202–208. [[CrossRef](#)]
16. Zhao, R.; Neighbour, G.; Han, J.J.; McGuire, M.; Deutz, P. Using game theory to describe strategy selection for environmental risk and carbon emissions reduction in the green supply chain. *J. Loss Prev. Proc.* **2012**, *25*, 927–936. [[CrossRef](#)]
17. Tian, Y.; Govindan, K.; Zhu, Q. A system dynamics model based on evolutionary game theory for green supply chain management diffusion among Chinese manufacturers. *J. Clean. Prod.* **2014**, *80*, 96–105. [[CrossRef](#)]
18. Liang, X.; Peng, Y.; Shen, G.Q. A game theory based analysis of decision making for green retrofit under different occupancy types. *J. Clean. Prod.* **2016**, *137*, 1300–1312. [[CrossRef](#)]

19. Cohen, C.; Pearlmutter, D.; Schwartz, M. Promoting green building in Israel: A game theory-based analysis. *Build. Environ.* **2019**, *163*, 106227. [[CrossRef](#)]
20. Barari, S.; Agarwal, G.; Zhang, W.J.; Mahanty, B.; Tiwari, M.K. A decision framework for the analysis of green supply chain contracts: An evolutionary game approach. *Expert Syst. Appl.* **2012**, *39*, 2965–2976. [[CrossRef](#)]
21. Qian, Q.K.; Chan, E.H.W.; Visscher, H.J.; Lehmann, S. Modeling the green building (GB) investment decisions of developers and end-users with transaction costs (TCs) considerations. *J. Clean. Prod.* **2015**, *109*, 315–325. [[CrossRef](#)]
22. Chen, Q.; Liu, P.H.; Chen, C.T. Evolutionary game analysis of government and enterprises during promotion process of prefabricated construction. *J. Interdiscip. Math.* **2017**, *20*, 1587–1593. [[CrossRef](#)]
23. Coninx, K.; Deconinck, G.; Holvoet, T. Who gets my flex? An evolutionary game theory analysis of flexibility market dynamics. *Appl. Energy* **2018**, *218*, 104–113. [[CrossRef](#)]
24. Wang, M.; Lian, S.; Yin, S.; Dong, H.M. A three-player game model for promoting the diffusion of green technology in manufacturing enterprises from the perspective of supply and demand. *Mathematics* **2020**, *8*, 1585. [[CrossRef](#)]
25. Teng, Y.; Pan, W. Systematic embodied carbon assessment and reduction of prefabricated high-rise public residential buildings in Hong Kong. *J. Clean. Prod.* **2019**, *238*, 117791. [[CrossRef](#)]
26. Wang, J.; Qin, Y.; Zhou, J. Incentive policies for prefabrication implementation of real estate enterprises: An evolutionary game theory-based analysis. *Energy Policy* **2021**, *156*, 112434. [[CrossRef](#)]
27. Dou, Y.; Xue, X.; Zhao, Z.; Luo, X. Factors influence China's off-site construction technology innovation diffusion. *Sustainability* **2019**, *11*, 1849. [[CrossRef](#)]
28. Page, K.M.; Nowak, M.A. Unifying evolutionary dynamics. *J. Theor. Biol.* **2002**, *219*, 93–98. [[CrossRef](#)]
29. Friedman, D. Evolutionary games in economics. *J. Economet. Soc.* **1991**, *59*, 637–666. [[CrossRef](#)]
30. Kamar, K.A.M.; Hamid, Z.A.; Ghani, M.K.; Rahim, A.H.A.; Zain, M.Z.M.; Ambon, F. Business strategy of large contractors in adopting industrialised building system (IBS): The Malaysia case. *J. Eng. Sci. Technol.* **2012**, *7*, 774–784.
31. Shi, L.; Wang, X.; Hou, H. Research on Optimization of array honeypot defense strategies based on evolutionary game theory. *Mathematics* **2021**, *9*, 805. [[CrossRef](#)]
32. Bai, Y.; Song, S.; Jiao, J.; Yang, R. The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. *J. Clean. Prod.* **2019**, *233*, 819–829. [[CrossRef](#)]
33. Huang, X.; Hu, Z.; Liu, C.; Yu, D.; Yu, L. The relationships between regulatory and customer pressure, green organizational responses, and green innovation performance. *J. Clean. Prod.* **2016**, *112*, 3423–3433. [[CrossRef](#)]