Research on the Development Policy of Prefabricated Building based on asymmetric Evolutionary Game

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Abstract. With the rapid development of modern society and economy and the continuous acceleration of industrialization in China, the transformation and upgrading of the construction industry is imminent, meanwhile, the development of prefabricated building is a strong starting point at present. In order to promote the healthy and rapid development of prefabricated construction market, the government should play a leading role and provide effective incentives to construction enterprises and consumers. This paper takes the theory and method of game theory as the tool, constructs the game model of government-construction enterprise, government-consumer respectively, and then uses Matlab to verify the model analysis results. Finally, it is concluded that a sound compensation system issued by the government to alleviate the financial pressure of construction enterprises and consumers is an important factor to promote the development of the market at present, and the best guidance strategies and suggestions are put forward for the government.

1. Introduction
Prefabricated buildings are not only efficient, energy saving and environmental protection, but also conducive to promoting the development of digital information technology in the field of construction, which will be the main force of China's industrial reform. Many scholars have studied the factors that promote the development of prefabricated construction market. From the existing literature, for construction enterprises and consumers, economic incentives are the main factors that promote the development of the market. For the government, the improvement of social and environmental benefits is the driving force to promote the development of the market. Although there are many researches, the level of prefabricated buildings in China still lags behind that of foreign countries with mature technology, and the promotion effect does not reach the expected level. In the early stage of market development, only relying on the market's own regulation ability will not be able to achieve the goal. Therefore, the government's guidance and incentive role is particularly important.

Based on the game theory, this paper constructs the government-construction enterprise and government-consumer game models, and obtains the optimal solution of agent behavior decision by analyzing the decision-making and evolution path of different subjects, and puts forward some
strategic suggestions for the government to promote the development of prefabricated building market.

2. Behavior analysis of three participants in prefabricated construction market

The government's role in promoting the development of the prefabricated construction market is intangible and critical. The relevant policies introduced by the government guide the development direction of the market and give support and incentives to other participants in the market. Most of the government's current policies are fiscal policies aimed at easing the financial pressure on enterprises, with less investment in scientific research and innovation throughout prefabricated construction projects. Only a handful of local governments have introduced fiscal subsidies to consumers. In addition, the prefabricated market lacks policies for industrial standardization.

After obtaining development and construction funds through financing and other means, construction enterprises purchase land from the government, and then carry out the development design, construction, and operation of buildings. Enterprises hope to gain benefits from the production and sales of buildings, so their own economic benefits are the primary reference standard for their decision-making. Due to the immature processing technology and insufficient construction level of the parts in China, the cost and sales difficulty of building prefabricated buildings are high, so the enthusiasm of building enterprises to develop and build prefabricated buildings is low.

Consumers in the prefabricated construction market are buyers and potential buyers of prefabricated buildings with two main considerations -- price and quality. In terms of price, the price of prefabricated buildings is higher than that of traditional cast-in-place buildings due to immature technology, which discourages consumers. In terms of consumer psychology, consumers have a wait-and-see attitude towards the safety and livability of prefabricated buildings. Moreover, the consumer awareness of environmental protection in China is weak, and the energy-saving and environmental protection advantages of prefabricated buildings cannot attract large-scale consumers to buy. As a result, consumers have insufficient purchasing power.

3. Game analysis between the government and other participants

3.1 Construction of government-construction enterprise game model

In the government-construction enterprise game model, both the government and the construction enterprise get incomplete information, and the model is an asymmetric evolutionary game. The government has two strategic choices, namely to adopt proactive policy and laissez-faire policy towards construction enterprises. Construction companies also have two strategic choices: prefabricated buildings and traditional buildings. The model parameters are set as follows:

- $A$, additional cost when the government adopts active policies;
- $B$, the basic income when the government adopts laissez-faire policy, refers to the income minus the cost;
- $\Delta B$, the incremental benefit of proactive government policies, was positively correlated with the resource utilization rate of prefabricated buildings;
- $C$, The cost of financial subsidies to construction enterprises when the government adopts active policies;
- $D$, additional costs for construction firms to build prefabricated buildings;
- $E$, the basic income of construction enterprises choosing to build traditional buildings refers to the construction income minus the construction cost;
- $\Delta E$, the incremental revenue of construction enterprises building prefabricated buildings is positively correlated with the resource utilization rate of building prefabricated buildings;$F$,when the government adopts active policies, enterprises fail to meet relevant standards because they choose to build traditional buildings.;
- $\beta$, The ratio of resource utilization level of construction enterprises under laissez-faire policy to resource utilization under active policy is $\beta$ ($0<\beta<1$).

According to the market externality theory and the basic behavior hypothesis of government and construction enterprises, an asymmetric evolutionary game matrix of two-party game is constructed, as shown in Table 1:

|                  | prefabricated buildings | traditional buildings |
|------------------|-------------------------|-----------------------|
| $(y)$            | $A + B - \Delta B$      | $D + E - \Delta E$    |
| $(1-y)$          | $A + B - C$             | $D + E - \beta E$     |

According to the market externality theory and the basic behavior hypothesis of government and construction enterprises, an asymmetric evolutionary game matrix of two-party game is constructed, as shown in Table 1:
3.2 Analysis of game model between government and construction enterprises

In the initial state, it is assumed that the probability of the government adopting proactive policies is \( x (0 \leq x \leq 1) \) and the probability of adopting laissez-faire policies is \( 1-x \). The probability of building enterprises to build prefabricated buildings is \( y (0 \leq y \leq 1) \), and the probability of building traditional buildings is \( 1-y \). Moreover, it is assumed that the strategies of both sides of the game are pure strategies.

(1) Dynamic replication analysis

When the government adopted proactive policy and laissez-faire policy, the expected benefits were \( U_{g1} \) and \( U_{g2} \) respectively, and the average expected benefits were \( U_{g3} \).

\[
U_{g1} = y(-A + B + \Delta B - C) + (1-y)(-A + B) = y(\Delta B - C) - A + B
\]

\[
U_{g2} = y(B + \beta \Delta B) + (1-y)B = B + y\beta \Delta B
\]

\[
U_{g3} = xU_{g1} + (1-x)U_{g2} = xy(\Delta B - C - \beta \Delta B - Ax + B + y\beta \Delta B)
\]

The dynamic replication equation of the government:

\[
F(x) = \frac{dx}{dt} = x(U_{g1} - U_{g3}) = x(1-x)[y(\Delta B - C - \beta \Delta B) - A] = x(1-x)[y(\Delta B - C - \beta \Delta B) - A]
\]

Let \( F(x) = 0 \), we get \( x_1 = 0, x_2 = 1, y^* = \frac{A}{\Delta B - C - \beta \Delta B} \).

According to the stability theorem of the dynamic replication equation, it can be seen that:

- \( y = y^* \), \( F(x) = 0 \), that is, the evolution and stability strategy of the government is random.
- \( y < y^* \), \( F'(0) < 0 \), that is, the evolution and stability strategy of the government is laissez-faire policy.
- \( y > y^* \), \( F'(0) < 0 \), that is, the evolution and stability strategy of the government is proactive policy.

The expected earnings of prefabricated buildings and traditional buildings are \( U_{e1} \) and \( U_{e2} \) respectively, and the average expected earnings are \( U_{e3} \).

\[
U_{e1} = x(-D + E + \Delta E + C) + (1-x)(-D + E + \beta \Delta E) = -D + E + \beta \Delta E + x(\Delta E + C - \beta \Delta E)
\]

\[
U_{e2} = x(E - F) + (1-x)E = E - xF
\]

\[
U_{e3} = yU_{e1} + (1-y)U_{e2} = xy(\Delta E + C - \beta \Delta E + F) - xF + E + y(-D + \beta \Delta E)
\]

The dynamic replication equation of the building enterprises:

\[
F(y) = \frac{dy}{dt} = yU_{e1} + (1-y)U_{e2} = y(1-y)(U_{e1} - U_{e2})
\]

\[
= y(1-y)[x(\Delta E + C - \beta \Delta E + F) - D + \beta \Delta E]
\]

Let \( F(y) = 0 \), we get \( y_1 = 0, y_2 = 1, x^* = \frac{D - \beta \Delta E}{\Delta E + C - \beta \Delta E + F} \).

According to the stability theorem of the dynamic replication equation, it can be seen that:

- \( x = x^*, F(y) = 0 \), that is, the evolutionary stabilization strategy is random.
- \( x < x^*, F'(0) < 0 \), that is, the evolutionary stabilization strategy is traditional buildings.
- \( x > x^*, F'(0) < 0 \), that is, the evolutionary stabilization strategy is prefabricated buildings.

(2) Analysis on the stability of evolvement strategy of game model

A two-dimensional plane coordinate system is used to represent the dynamic replication equation of the government and the construction enterprise, and the phase diagram describes the dynamic
The evolution process of the government and the construction enterprise, as shown in Figure 1:

![Figure 1](image_url)

Figure 1 The dynamic evolution of the behavior of government and construction enterprises

In Figure 1, there are five local equilibrium points O, A, B, C, and D, and two convergent equilibrium points O (0,0) and B (1, 1). The area of graph OACD is denoted as $S_1$, and the area of graph ABCD is denoted as $S_2$, respectively indicating the probability that the game model eventually converges to O and B. To increase the probability that the ultimate evolutionary stabilization strategy is (proactive policy, prefabricated building), the area of graph ABCD $S_2 = 1 - \frac{1}{2} \left( \frac{A}{\Delta G - \beta \Delta E} + \frac{D - \beta \Delta E}{\Delta E + C - \beta \Delta E + F} \right)$ needs to be expanded.

3.2.1 Construction of government-consumer game model

In the government-consumer game model, both the government and consumers get incomplete information, and the model is an asymmetric evolutionary game. The government has two strategic choices: namely incentive policy for consumers and laissez-faire policy. Consumers also have two strategic choices: buy prefabricated buildings and buy traditional buildings. The parameters of the model are set as follows: $G$, the basic income when the government adopts laissez-faire policy, refers to the income after deducting the cost; $H$, the additional cost when the government adopts incentive policies; $\Delta G$, the incremental benefit when the government adopts incentive policies; when the incentive policies do not receive positive responses from consumers, the incremental benefit is $\alpha \Delta G$ ($0 < \alpha < 1$); $I$, When the government adopts laissez-faire policy, consumers' purchase of prefabricated buildings adds extra income to the government; $K$, the cost of financial subsidy when the government adopts incentive policies; $L$, the basic income from the purchase of traditional buildings by consumers, refers to the income from the use value after deducting the purchase cost; $\Delta L$, incremental benefit of consumers' purchase of prefabricated buildings; $\gamma \Delta L$ ($0 < \gamma < 1$) was obtained when the government adopted laissez-faire policy for consumers' purchase behavior. $M$, the additional cost for consumers to purchase prefabricated buildings.

According to the market externality theory and the basic behavior hypothesis of government and construction enterprises, an asymmetric evolutionary game matrix of two-party game is constructed, as shown in Table 2:

|              | buy prefabricated buildings | buy traditional buildings |
|--------------|-----------------------------|---------------------------|
| incentive policy | $G-H+\Delta G-K$, $L+\Delta L+K-M$ | $G-H+\alpha \Delta G$, $L$ |
| $(x)$         |                             |                           |
| laissez-faire policy | $G+I$, $L+\gamma \Delta L-M$ | $G$, $L$                |
| $(1-x)$      |                             |                           |
3.2.2 Analysis of game model between government and consumer

In the initial state, it is assumed that the probability of the government adopting incentive policies is \(x\) (\(0 \leq x \leq 1\)) and the probability of adopting laissez-faire policies is \(1-x\). The probability of consumer to 
buy prefabricated buildings is \(y\) (\(0 \leq y \leq 1\)), and the probability of buy traditional buildings is \(1-y\).

Moreover, it is assumed that the strategies of both sides of the game are pure strategies.

(1) Dynamic replication analysis

When the government adopted incentive policy and laissez-faire policy, the expected benefits were \(U_{g1}\) and \(U_{g2}\) respectively, and the average expected benefits were \(U_{g3}\).

\[
U_{g1} = y(G - H + \Delta G - K) + (1-y)(G - H + \alpha \Delta G) \\
U_{g2} = y(G + I) + (1-y)G = G + yI \\
U_{g3} = xU_{g1} + (1-x)U_{g2} = xy(\Delta G - K - \alpha \Delta G - I) + x(\alpha \Delta G - H) + G + yI
\]

The dynamic replication equation of the government:

\[
F(x) = \frac{dx}{dt} = x(U_{g1} - U_{g3}) = x(1-x)(U_{g1} - U_{g2}) = x(1-x)[y(\Delta G - K - \alpha \Delta G - I) + \alpha \Delta G - H]
\]

Let \(F(x) = 0\), we get \(x_1 = 0\), \(x_2 = 1\), \(y^* = \frac{H - \alpha \Delta G}{\Delta G - K - \alpha \Delta G - I}\)

According to the stability theorem of the dynamic replication equation, it can be seen that:

\(x = x^*\), \(F(x) = 0\), that is, the evolutionary stabilization strategy of the government is random.

\(x < x^*, F'(0) < 0\), that is, the evolutionary stabilization strategy of the government is laissez-faire policy.

\(x > x^*, F'(0) < 0\), that is, the evolutionary stabilization strategy of the government is incentive policy.

It is assumed that consumers’ expected earnings from purchasing prefabricated buildings and 
traditional buildings are \(U_{c1}\) and \(U_{c2}\), respectively, and the average expected earnings are \(U_{c3}\).

\[
U_{c1} = x(L + \Delta L + K - M) + (1-x)(L + \gamma \Delta L - M) = L - M + \gamma \Delta L + x(\Delta L + K - \gamma \Delta L) \\
U_{c2} = xL + (1-x)L = L \\
U_{c3} = yU_{c1} + (1-y)U_{c2} = xy(\Delta L + K - \gamma \Delta L) + L + y(\gamma \Delta L - M)
\]

The dynamic replication equation of the government:

\[
F(y) = \frac{dy}{dt} = y(U_{c1} - U_{c3}) = y(1-y)(U_{c1} - U_{c2}) = y(1-y)[x(\Delta L + K - \gamma \Delta L) + \gamma \Delta L - M]
\]

Let \(F(y) = 0\), we get \(y_1 = 0\), \(y_2 = 1\), \(x^* = \frac{H}{\Delta L + K - \gamma \Delta L + M}

According to the stability theorem of the dynamic replication equation, it can be seen that:

\(x = x^*, F(y) = 0\), that is, the evolutionary stabilization strategy is random.

\(x < x^*, F(0) < 0\), that is, the evolutionary stabilization strategy is buying traditional buildings.

\(x > x^*, F(0) < 0\), that is, the evolutionary stabilization strategy is buying prefabricated buildings.

(2) Analysis on the stability of evolvement strategy of game model

A two-dimensional plane coordinate system is used to represent the dynamic replication equation 
of the government and the consumer, and the phase diagram describes the dynamic evolution process 
of the government and the consumer, as shown in Figure 2:

![Figure 2 The dynamic evolution of the behavior of government and consumer](image)
In figure 2, there are five local equilibrium points O, P, Q, R, S, and two convergence equilibrium points O (0,0), R (1,1). The area of graph OPQS is denoted as $S_3$, and the area of graph PQRS is denoted as $S_4$, respectively indicating the probability that the game model eventually converges to O and R. To increase the probability that the ultimate evolutionary stabilization strategy is (incentive policy, purchase of prefabricated buildings), the area of the graph $S_4 = 1 - \frac{1}{2} (\frac{H-a\Delta G}{\Delta G - K - a\Delta G - l} + \frac{-\gamma \Delta L + M}{\Delta L + K - \gamma \Delta L})$ needs to be expanded.

### 3.3 Game strategy analysis

In the government-construction enterprise game model, from the perspective of government behavior analysis, the following measures are obtained to promote market development. The government should reasonably control the policy cost and capital input when adopting proactive policies. It has also increased penalties for firms that fail to meet standards and offered richer hidden benefits to firms that build prefabricated buildings. And good social benefits can increase the probability that the government takes active policies to promote the rapid development of prefab construction market.

In the government-consumer game model, from the perspective of government behavior analysis, the following conclusions are drawn: When the government adopts incentive policies, it is necessary to reasonably control policy costs and capital input, fully understand consumers' psychology, and improve their environmental awareness. At the same time, we should strengthen the preferential policies for buyers and formulate more abundant and targeted preferential policies. In addition, the government also needs to strictly control the quality of prefab buildings, improve relevant supporting facilities, and reduce the psychological pressure and risks borne by consumers.

### 4. Simulation analysis

In order to more clearly demonstrate the influence process of various relevant parameters in the prefabricated building market on the final evolution result and verify the analysis conclusions of the above two game models, this paper uses Matlab software to simulate the evolution paths of the two sides affected by the government's behavior decision in the game model.

#### 4.1 Government - construction enterprise game model simulation

In the government-construction enterprise game model, in order to make the final evolution result (1,1), (active policy, prefabricated building construction), it is necessary to ensure that all parameters are satisfied: $\Delta B - C - \beta \Delta B > 2A, 2D - \Delta E - C - F < \beta \Delta E$. In this paper, the initial values are set as $A=1, \Delta B=10, C=1, D=3, \Delta E=8, F=6, \beta=0.3$.

The impact of penalties($F$) for non-compliance by construction enterprises changes is shown in the Figure3:

![Figure3](attachment:image.jpg)

(1) $F=2(2) F=4$
The impact of penalties ($F$) for non-compliance by construction enterprises changes. The punishment in the figure 1(2) is relatively light. When the initial proportion of the government and construction enterprises adopting proactive policies and choosing to build prefabricated buildings is very low, the final evolution result is (0,0), but its probability decreases with the increase of incremental income. When the initial ratio is high, the time of its evolution to the stable strategy (1,1) does not become shorter with the increase of the penalty intensity. The punishment intensity in the figure 3(4) is relatively heavy. The ultimate evolutionary stabilization strategy of both the government and the construction enterprise is (1,1), but only when the initial proportion is low, the evolution speed is accelerated with the aggravation of the punishment intensity.

4.2 Government - consumer game model simulation

In the government-consumer game model, in order to make the final evolution result (1,1), (incentive policy, prefabricated building construction), it is necessary to ensure that all parameters are satisfied: $2H+K+I < a \Delta G + \Delta G , 2M-K < \gamma \Delta L + \Delta L$. In this paper, the initial values are set as $G=2, H=1, \Delta G=10, I=3, K=2, L=1, \Delta L=5, M=4, a=0.2, \gamma=0.3$.

The impact of the government's proactive policy on financial subsidies ($K$) changes is shown in the Figure 4:
In the government-consumer game model, the government evolves to the ultimate stabilization strategy -- the time to adopt incentive policies increases with the increase of financial subsidies, while the consumer evolves to the ultimate stabilization strategy -- the time to purchase prefabricated buildings decreases with the increase of financial subsidies. It can be seen that increasing financial subsidy input has a positive effect on consumers' behavior strategy and a negative effect on the government.

4.3 Analysis of simulation results

Through the simulation analysis of the two game models, the results verify the conclusion of the analysis of influencing factors in the game model: the higher the initial proportion of the government to adopt proactive policies, the more favorable it is for the development of prefabricated construction market; The government's financial subsidies for consumers are crucial in the early stage of market development, but in the middle and later stage of market development, with the increase of the cost of financial subsidies, the government needs to strike a balance between cost and incentive effect. Increasing the punishment of substandard construction enterprises only has an incentive effect in the early stage of market development, and other incentive measures are needed in the middle and later stage of market development.

5. Policy suggestions

This paper constructs two game models of government - construction enterprise and government - consumer, analyzes the simulation data, and focuses on the government strategy to promote the development of prefab building market. Through the conclusion of the model analysis, the following government strategy recommendations are drawn:

1) In the early stage of market development, the government should give priority to economic incentives. For construction enterprises and consumers to develop corresponding fee waiver policies, such as lower loan interest rates, lower taxes, lower lending standards. At the same time, the construction enterprises will be encouraged to optimize the project process by increasing research funding.

2) With the development of the market, the government should gradually reduce the financial subsidies to construction enterprises and consumers. The government needs to plan ahead and change its financial subsidy policy in stages according to the changes of construction companies and consumers until the subsidy is finally removed.

3) The government should establish and improve industry standards and standardize market development. The improvement of the corresponding industry standards is conducive to the balanced development of all construction enterprises, improve the overall level of the industry. Moreover, it can
eliminate consumers' concerns, reduce consumers' buying risks, and promote the benign development of the market.

(4) The government should formulate detailed and reasonable punishment policies. In the early stage of market development, increasing penalties for enterprises that fail to meet pollution control standards will help construction enterprises transform and promote the development of prefab construction market. The punishment policy should be comprehensive and targeted, but should not be too strong.

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