Analysis on the Incentive Policy of Traditional Construction Model and Prefabricated Construction Model Based on Evolutionary Game Theory

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Abstract. The development of prefabricated construction model is a major change in construction production methods. It is an important measure to promote supply-side structural reform and the development of new urbanization. It is conducive to saving resources and energy consumption, reducing construction pollution, shortening construction period and improving engineering quality and safety. It is also conducive to promoting the deep integration of the construction industry and informatization industrialization, cultivating new industries, and promoting the resolution of excess capacity. In the promotion and implementation of this model, the positive incentives given by government departments are the compass to guide the steady progress of this model. This article analyzes the transmission mechanism of the incentive policy of the prefabricated construction model in China in this behavior based on evolutionary game theory, and puts forward some suggestions on how to improve China’s prefabricated construction model policy system.

1. The Development Status of Prefabricated Construction Model
The prefabricated construction model means that part or all of the components of the building are produced in the component prefabrication factory, and then transported to the construction site through the corresponding transportation method, and the components are assembled by reliable installation methods and installation machinery to become a building with use functions building construction methods. Compared with the traditional construction model, it has the advantages of short construction period, less resource consumption, energy saving and environmental protection [1]. This model is a representative of the industrialization of construction and the inevitable trend of the transformation and upgrading of the construction industry to the modernization of the construction industry to achieve sustainable development.

Developed countries such as the United Kingdom [2], the United States, and Japan began to develop the modernization of the construction industry in the last century. The proportion of buildings constructed by model methods in the United Kingdom was as high as 80%, and that in Japan and the United States reached more than 70%. However, the modernization of the construction industry in China started late. In recent years, with the rapid economic development and the improvement of technical level, the processing accuracy and quality of prefabricated components in China, assembling construction technology and management level have gradually improved. Since the "Guiding Opinions of the General Office of the State Council on Vigorously Developing Prefabricated Construction" in 2016, 31 provinces (autonomous regions and municipalities) across the country have successively
issued a series of relevant policy documents to promote the development of prefabricated construction. From 2016 to 2019, the number of policy documents related to prefabricated construction were 33, 157, 235, and 261 respectively. In 2019, the proportion of newly started prefabricated construction in key areas (the three major urban agglomerations of Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta) accounted for 47.1% of the country. It can be seen that there is a lot of room for the development of the prefabricated construction model in China.

2. The Challenges in the Large-scale Promotion of Prefabricated Construction Model

Promoting the prefabricated construction model across the country faces two challenges, one is cost, and the other is concept. The standardization, specialization, and scale of the production of prefabricated construction are low, and the technical standards for prefabricated construction are different from those of the traditional construction model (Cast-in-place concrete building). These lead to high production costs. Due to short-term cost considerations, real estate companies are unwilling to actively choose the prefabricated construction model. Conceptually, it cannot equate the prefabricated construction with the prefabricated reinforced concrete assembly, as well as the wood structure assembly type and the steel structure assembly type. It also cannot equate prefabricated construction with the main structure assembly. Wall panels, pipelines, and interior decoration are all content of prefabricated construction. Construction enterprises should fully understand the prefabricated construction model, understand the government's policies and regulations on prefabricated construction. It will promote the scale effect and driving effect of the prefabricated construction model, while also reduce its construction cost.

Therefore, on the one hand, the government must publicize, call for, and improve supporting policies related to prefabricated construction. On the other hand, it must formulate reasonable incentive policies to bring more economic support, update and improve related technical standards for prefabricated construction, and optimize existing prefabricated construction policies, provide institutional guarantee and technical support for the development of prefabricated construction.

3. The Evolutionary Game Analysis of Government and Real Estate Enterprises

3.1. Basic Assumptions and Model Establishment

The entire evolutionary game system has two main bodies, the government and the real estate enterprise. The government's incentive policies are spiritual incentives and economic incentives. Among them, spiritual incentives include government propaganda and calls, and no policy support. Economic incentives include a series of preferential policies formulated by the government to provide preferential support to related enterprises.

Both sides of the evolutionary game have bounded rationality. Each party’s game strategy is based on the opponent’s strategy to build its own strategy choice. For example, the government cannot master all relevant information about real estate companies, but it is rational to analyze policies. It is rational.

Under the above assumptions, set the variables that affect the payment function of both parties in the game. When the real estate enterprise adopts the traditional construction model, the government benefit is $a_1$, and the enterprise benefit is $a_2$. When the real estate enterprise adopts the prefabricated construction model, the government benefit is $b_1$, and the enterprise benefit is $b_2$. On this basis, when the government adopts economic incentive policies, the government’s long-term benefit is $b_3$, and the social benefit is $b_4$. When the government adopts the spiritual incentive policy, the long-term benefit obtained by the government is $b_5$. When the real estate company adopts the prefabricated construction model, the long-term benefit obtained on the brand reputation is $b_6$. The cost when the government adopts economic incentive policies is $c_1$. Various subsidies and preferential support for real estate companies that adopt the prefabricated construction model are $c_2$. Compared with the traditional construction model, the cost of real estate enterprises adopting the prefabricated construction model is
c_3 [3]. So the construction of evolutionary game model between government and real estate enterprises is shown in table 1.

**Table 1.** Construction of evolutionary game model between government and real estate enterprises.

| Government Real estate | Prefabricated construction model | Traditional construction model |
|------------------------|----------------------------------|-----------------------------|
| Economic incentives    | \( b_1 + b_2 + b_3 - c_1 - c_2 \) | \( a_1 - c_1, a_2 \)      |
|                        | \( b_1 + b_2 + c_3 - c_4 \)      |                             |
| Spiritual incentives   | \( b_1 + b_2 + b_3 - c_3 \)      | \( a_1, a_2 \)             |

3.2. **Evolutionary Stability Strategy Analysis**

Construct the desired function as follows [4, 5]:

When the government adopts economic incentive policies, the government's benefit is:

\[
U_1 = y(b_1 + b_2 + b_3 - c_1 - c_2) + (1 - y)(a_1 - c_1)
\] (1)

When the government adopts spiritual incentive policy, the government's benefit is:

\[
U_2 = y(b_1 + b_2) + (1 - y)a_1
\] (2)

The government’s average expected income \( U \) is:

\[
U = xU_1 + (1-x)U_2 = xy(b_1 + b_2 - b_3 - c_2) - xc_1 + y(b_1 + b_2 - a_1) + a_i
\] (3)

According to the above benefits, the dynamic equation for replication is:

\[
F(x) = \frac{dx}{dt} = x(U_1 - U) = x(1-x)(U_1 - U_2) = x(1-x)(b_1 + b_2 - b_3 - c_2)y - c_1
\] (4)

Let \( \frac{dx}{dt} = 0 \), then the steady state of the dynamic equation can be found:

\[
x_i^* = 0
\]

\[
x_i^* = 1
\]

\[
x^* = \frac{c_i}{b_1 + b_2 - b_3 - c_2}
\]

When the real estate company adopts the prefabricated construction model, the benefit that the company obtains is:

\[
U'_1 = x(b_2 + b_3 + c_2 - c_1) + (1-x)(b_2 + b_3 - c_1)
\] (5)

When the real estate company adopts the traditional construction model, the benefit that the company obtains is:

\[
U'_2 = xa_2 + (1-x)a_2
\] (6)

The enterprise’s average expected income \( U' \) is:

\[
U' = yU'_1 + (1-y)U'_2 = y(xc_2 + b_2 + b_3 - a_2 - c_3) + a_2
\] (7)

According to the above benefits, the dynamic equation for replication is:

\[
F(y) = \frac{dy}{dt} = y(U'_1 - U') = y(1-y)(U'_1 - U'_2) = y(1-y)(xc_2 + b_2 + b_3 - a_2 - c_3)
\] (8)
Let \( \frac{dy}{dt} = 0 \), then the steady state of the dynamic equation can be found:

\[
\begin{align*}
y_1^* &= 0 \\
y_2^* &= 0 \\
y^* &= \frac{a_2 + a_3 - b_2 - b_6}{c_2}
\end{align*}
\]

Hirshleifer pointed out that a trajectory starting from an arbitrary small neighborhood of a certain equilibrium point of a dynamic system eventually tends to this equilibrium point. It means that the equilibrium point has gradual stability and it is called the evolutionary equilibrium point. When the proportion of the two sides of the game adopting a specific strategy reaches the equilibrium point, it will no longer change, maintaining stability against minor disturbances. Through the above analysis, it can be concluded that there are five equilibrium points \((0,0)\), \((1,0)\), \((0,1)\), \((1,1)\), \((x^*, y^*)\) in the evolutionary game model of the prefabricated construction model between the government and the real estate enterprise group.

According to Friedman’s research, the stability of the equilibrium point of an evolutionary system can be obtained from the local stability analysis of its Jacobian matrix. According to equation (4) and equation(8), then the Jacobian matrix \( J \) is:

\[
\begin{pmatrix}
(1-2x)(b_3+b_4-a_2-c_2)y-c_1 \\
(y-y^2)c_2 \\
(x-x^2)(b_3+b_4-a_2-c_2) \\
(1-2y)(c_2x+b_2+b_6-a_2-c_1)
\end{pmatrix}
\]

Analyze the stability of each equilibrium point under the following 4 situations. The determinant values \((\text{Det})\) and signs of the Jacobian matrix \((\text{Tr})\) can be divided into the following tables 2-5.

**Table 2.** Stable results of system evolution. \((b_3+b_4-a_2-c_2-c_1<0, b_2+b_6+c_2-a_1-c_3<0)\)

| Equilibrium point \((x,y)\) | The sign of \(\text{Det}(J)\) | The sign of \(\text{Tr}(J)\) | Result          |
|-----------------------------|-----------------------------|-----------------------------|-----------------|
| \((0,0)\)                  | +                          | -                           | ESS             |
| \((0,1)\)                  | +                          | Uncertain                   | Saddle point    |
| \((1,0)\)                  | +                          | Uncertain                   | Saddle point    |
| \((1,1)\)                  | +                          | +                           | Unstable point  |

**Table 3.** Stable results of system evolution. \((b_3+b_4-a_2-c_2-c_1>0, b_2+b_6+c_2-a_1-c_3<0)\)

| Equilibrium point \((x,y)\) | The sign of \(\text{Det}(J)\) | The sign of \(\text{Tr}(J)\) | Result          |
|-----------------------------|-----------------------------|-----------------------------|-----------------|
| \((0,0)\)                  | +                          | -                           | ESS             |
| \((0,1)\)                  | +                          | +                           | Unstable point  |
| \((1,0)\)                  | -                          | Uncertain                   | Saddle point    |
| \((1,1)\)                  | -                          | Uncertain                   | Saddle point    |

**Table 4.** Stable results of system evolution. \((b_3+b_4-a_2-c_2-c_1<0, b_2+b_6+c_2-a_1-c_3>0)\)

| Equilibrium point \((x,y)\) | The sign of \(\text{Det}(J)\) | The sign of \(\text{Tr}(J)\) | Result          |
|-----------------------------|-----------------------------|-----------------------------|-----------------|
| \((0,0)\)                  | +                          | -                           | ESS             |
| \((0,1)\)                  | -                          | Uncertain                   | Saddle point    |
| \((1,0)\)                  | +                          | +                           | Unstable point  |
| \((1,1)\)                  | -                          | Uncertain                   | Saddle point    |
Table 5. Stable results of system evolution. \((b_3+b_6-b_5-c_2-c_1>0, b_2+b_6+c_2-a_1-c_3>0)\)

| Equilibrium point \((x, y)\) | The sign of \(\text{Det}(J)\) | The sign of \(\text{Tr}(J)\) | Result |
|-------------------------------|-----------------------------|-----------------------------|--------|
| \((0,0)\) | + | - | ESS |
| \((0,1)\) | + | + | Unstable point |
| \((1,0)\) | + | + | Unstable point |
| \((1,1)\) | + | - | ESS |
| \((x^*, y^*)\) | - | 0 | Saddle point |

A two-dimensional plan is used to represent the dynamic relationship between the two parties in the game.

![Figure 1. Schematic diagram of the replication dynamics and stability in the group game [3].](image)

It can be seen from table 2, table 3 and table 4, when the prefabricated construction model is adopted, the expected benefits obtained by real estate companies are lower than that of the traditional construction model, or the government’s expected benefits are lower than traditional construction models. There are only four equilibrium positions in evolution analysis, and there is only one point of evolutionary equilibrium, that is \((0,0)\) [6].

It can be seen from table 5, when the prefabricated construction model is adopted, the expected income obtained by real estate companies is higher than that of the traditional construction model. And the government’s expected benefits are higher than traditional construction model. In the figure 1, there will be five local equilibrium points, including two evolutionary equilibrium points. They are \((0,0)\) and \((1,1)\). In other words, the system can achieve the Pareto Optimality [7] only when \(b_3+b_2-b_5-c_2-c_1>0, b_2+b_6+c_2-a_1-c_3>0\). At this stage, the government adopts economic incentive policies, and real estate companies adopt the prefabricated construction model. Since the probabilities of both are non-negative, that is \(x^* \geq 0, y^* \geq 0\), so \(b_3+b_2-b_5-c_2>0, a_2+a_6-b_2-b_6>0\). Under all conditions, when the government adopts economic incentive policies, the cost of formulating and promoting relevant standards and policies should be at least: \(c_1>0\). When the government adopts economic incentive policies, the various subsidies and preferential support given to various real estate enterprises adopting the prefabricated construction model shall be: \(b_3+b_2-a_1-c_3\leq c_2<b_7+b_2-b_1-c_1\) [8, 9].

4. Conclusion
The goal of the government and real estate companies is to obtain higher profits and returns. At present, the key issues that affect the scale effect of the prefabricated construction model are cost and concept. The government’s development and promotion policy for the prefabricated construction model should continue to increase, and optimize the existing prefabricated construction policy system, formulate reasonable incentive policies [10], increase industry support, reduce unnecessary costs. Strengthen technical support for enterprises that adopt the prefabricated construction model, thereby
reducing the construction cost of the prefabricated construction model and increasing the economic benefits of real estate companies. Promote the government and real estate companies to use prefabricated construction model across the country, and then achieve the overall Pareto optimal state. To ensure that the prefabricated incentive mechanism is more standardized and rational, the future development of the prefabricated construction industry is worth looking forward to.

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