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Numerical Analysis on Diffusion Mechanism of Prefabricated Technology Under Government Intervention Based on Evolutionary Game

Abstract: The diffusion of prefabricated construction technology is an important guarantee for industrialization of construction industry. To investigate the roles of government, developers and contractors in the diffusion of prefabricated construction technology, a three-way evolutionary game model of prefabricated construction technology diffusion is introduced, and the influence of external factors related to game players on the diffusion of prefabricated construction technology is analyzed based on the evolutionary game model. With the numerical simulations conducted by system dynamics software of Vensim, the evolutionary trends under different initial conditions are dynamically displayed, and the results demonstrate that reducing the cost of diffusion assembly construction technology, is conducive to improving the enthusiasm of developers and contractors to share the prefabricated construction technology. Besides, appropriately increasing government incentives is conducive to promote the diffusion of prefabricated construction technology.

Keywords: Prefabricated Construction Technology, Government Intervention, Evolutionary Game Model, Numerical Simulation

I. INTRODUCTION

The "*14th Five-Year Plan for the Development of Construction Industry*" explicitly states that promoting prefabricated construction is a crucial approach to achieving industrialization in China's construction industry [1]. Compared to traditional construction methods, prefabricated construction offers various advantages such as resource conservation, shorter construction periods, lower energy consumption, and reduced pollution [2]. It represents a significant direction for the green, efficient, and low-carbon development of the construction industry [3]. Looking ahead, prefabricated construction will undoubtedly continue to play a pivotal role in advancing the achievement of the "carbon peaking and carbon neutrality" goals in the construction sector [4].

In recent years, with the initiative led by the State Council and the emphasis of local governments and construction management departments at all levels, the promotion and application of prefabricated construction technology in China have achieved certain results [5]. However, the development level of prefabricated construction technology in China is overall still relatively low, with limited application scope and significant regional disparities [6]. Currently, the willingness of the developers to adopt prefabricated construction technology is low [7], and the government lacks the relevant policy support [8]. Additionally, the proactive supply of prefabricated construction technology by contractors falls short of government expectations. These factors greatly restrict the application and development of prefabricated construction technology. As a result, the diffusion of prefabricated construction technology is crucial for studying the advanced technology's journey from research and development to promotion, from innovative achievements to economic benefits [9].

Prefabricated construction, much like traditional building practices, encompasses various processes including design, production, and installation [10]. It is also influenced by top-level policy frameworks and consumer purchasing preferences. Consequently, the diffusion of prefabricated construction technology involves multiple stakeholders, such as design firms, developers, contractors, government entities, and consumers [11]. Owing to various interactive uncertain factors, the optimum diffusion strategy for the prefabricated construction is highly dependent on the results of numerical simulation. Indeed, the numerical simulation is widely introduced to make the optimum choice for the development of prefabricated construction technology [12-14]. For example, Yan et al. [12] conducted the numerical simulation on the investment of prefabricated concrete buildings through the machine learning algorithm, verified that more reliable and reasonable investment estimation can be realized by the investment estimation model. Yin et al [13] conducted the MATLAB numerical simulation on the multi-objective optimization for coordinated production and transportation in the prefabricated construction, suggesting that the project efficiency enhancing and costs reducing of prefabricated construction is highly dependent on the on-site lifting. Du et al. [14] suggested more economic-efficient and environmentally friendly combination of emission trading scheme, government subsidies, and investment in low-carbon technology, based on the dynamic

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simulation on environmental policies effecting of the prefabricated building supply chain by software of Vensim. Therefore, it is essential to conduct the numerical simulation to optimize the diffusion strategy of prefabricated technology based on evolutionary game.

In the context of the government intervention, existing support policies primarily target developers and contractors [15], with fewer incentives directed towards design firms and consumers [16]. Developers and contractors encounter similar technological, organizational, and environmental factors during the diffusion of prefabricated construction technology, whereas design firms and manufacturers are less affected by organizational factors [11]. Furthermore, in the process of diffusing prefabricated construction technology, the government, developers, and contractors are considered bounded rational actors, engaging in trial and error and decision adjustments, thus falling within the realm of evolutionary game theory [17]. However, existing studies on evolutionary game theory have overlooked the interactive effects of decision-making among stakeholders in the market, specifically the impact of contractors' supply of prefabricated construction technology, focusing only on interactions between government and enterprises or enterprises and consumers, while neglecting the limited influence of consumers on the current stage of prefabricated construction technology diffusion [18]. Therefore, based on evolutionary game theory, this study selects developers and contractors as the adopters and providers of prefabricated construction technology, respectively. Moreover, the investigation on the factors that influence the diffusion of prefabricated construction technology, from the perspective of government incentives, is conducted by numerical simulations through system dynamics software of Vensim.

II. PREFABRICATED CONSTRUCTION TECHNOLOGY DIFFUSION GAME MODEL

The game model discussed in this paper revolves around the stakeholders involved in the diffusion process of prefabricated construction technology, namely the government, developers, and contractors. The hypotheses regarding their behavioral strategies are as follows:

Hypothesis 1: Asymmetric information prevails among three parties during the game, and each stakeholder consistently prioritizes their own interests. The game participants engage in a process of experimentation and correction, seeking optimal strategies throughout the evolutionary course of the tripartite game. To enhance the enthusiasm of developers and contractors in adopting prefabricated construction technology, the government provides certain policy support, including incentives and economic subsidies. Developers make decisions based on the assessment of benefits and costs associated with prefabricated construction technology, while contractors' decisions are consistently driven by profit-seeking motives.

Hypothesis 2: Government Behavioral Decision Hypothesis. The government's decision-making is assumed to have only two options, forming a decision set {incentive, no incentive}, with corresponding probabilities of $\{x, (1-x)\}$. When prefabricated construction technology is not adopted, the government's baseline benefits are denoted as A_1. When prefabricated construction technology is successfully adopted and diffused, the government gains social reputation and performance benefits denoted as A_2, as well as energy-saving and environmental benefits denoted as A_3. When the government chooses the "incentive" decision, it needs to provide developers and contractors with certain policy support and economic subsidies. The expenditure to incentivize developers is denoted as J, and the expenditure to incentivize contractors is denoted as L.

Hypothesis 3: Developer Behavioral Decision Hypothesis. Developers are assumed to have only two options for their decision-making, forming a decision set {adopt prefabricated construction technology, adopt cast-in-place construction technology}, with corresponding probabilities of $\{y, (1-y)\}$. When developers adopt cast-in-place construction technology, they incur a cost denoted as P_1 and obtain baseline benefits denoted as Q_1. When developers adopt prefabricated construction technology, they incur construction costs denoted as P_2, and the corresponding benefits are denoted as Q_2.

Hypothesis 4: Contractor Behavioral Decision Hypothesis. Contractors have two options for their decision-making, forming a decision set {supply prefabricated construction technology, supply cast-in-place construction technology}, with corresponding probabilities of $\{z, (1-z)\}$. When contractors supply cast-in-place construction technology, they incur construction costs denoted as M. The construction costs of prefabricated buildings are related to the minimum assembly rate enforced by the government[15]. The government imposes a minimum assembly rate standard on prefabricated building contractors. Let's use b to represent the cost increase factor for assembly rate, which means that when the minimum assembly rate is a, the construction costs of prefabricated buildings are $(1+ab)M$.

A. Model Construction

Based on the above-mentioned four basic hypotheses, the three-party payoff matrix related to the diffusion of prefabricated construction technology is shown in Tab. 1.

Table 1: Payoff Matrix

Game Entity	Government chooses "incentive" (x)		Government chooses "no incentive" ($1-x$)	
	Contractors "supply prefabricated construction technology" (z)	Contractors "supply cast-in-place construction technology" ($1-z$)	Contractors "supply prefabricated construction technology" (z)	Contractors "supply cast-in-place construction technology" ($1-z$)
Developers "adopt prefabricated construction technology" (y)	$A_1+A_2+A_3-J-L$ Q_2-P_2+J $P_2-(1+ab)M+L$	A_1 0 0	A_1+A_3 Q_2-P_2 $P_2-(1+ab)M$	A_1 0 0
Developers "adopt cast-in-place construction technology" ($1-y$)	A_1 0 0	A_1 Q_1-P_1 P_1-M	A_1 0 0	A_1 Q_1-P_1 P_1-M

According to the game payoff matrix in Tab. 1, we can calculate the expected payoffs for the government, developers, and contractors under different decisions, and then derive the replicator dynamic equations under the corresponding strategy conditions. The solution process is as follows:

When the government chooses the "incentive" decision, the expected payoff E_{z1} can be solved as shown in Equation (1):

$$E_{z1} = yz(A_2 + A_3 - J - L) + A_1 \tag{1}$$

When the government chooses the "no incentive" decision, the expected payoff E_{z2} can be solved as shown in Equation (2):

$$E_{z2} = yzA_3 + A_1 \tag{2}$$

The average expected payoff E_z for the government can be expressed as shown in Equation (3):

$$E_z = xE_{z1} + (1-x)E_{z2} \tag{3}$$

At this point, the replicator dynamic equation $G(x)$ for the government's "incentive" decision can be solved as shown in Equation (4):

$$G\left(x\right) = dx/dt = x(1-x)yz(A_2 - J - L) \tag{4}$$

When the developer chooses the decision of "adopting prefabricated construction technology", the expected payoff E_{k1} can be solved as shown in Equation (5):

$$E_{k1} = z(xJ + Q_2 - P_2) \tag{5}$$

When the developer chooses the decision of "adopting cast-in-place construction technology", the expected payoff E_{k2} can be solved as shown in Equation (6):

$$E_{k2} = (1-z)(Q_1 - P_1) \tag{6}$$

The average expected payoff E_k for the developer can be expressed as shown in Equation (7):

$$E_k = yE_{k1} + (1-y)E_{k2} \tag{7}$$

At this point, the replicator dynamic equation $G(y)$ for the developer's decision of "adopting prefabricated construction technology" can be solved as shown in Equation (8):

$$G\left(y\right) = dy/dt = (y - y^2)[z(xJ + Q_2 - P_2) - (1-z)(Q_1 - P_1)] \tag{8}$$

Similarly, the expected payoff for the contractor when they choose the decision of "supplying prefabricated construction technology", E_{c1}, can be solved as shown in Equation (9):

$$E_{c1} = y[P_2 - \left(1 + ab\right)M + xL] \tag{9}$$

The expected payoff for the contractor when they choose the decision of "supplying cast-in-place construction technology", E_{c2}, can be solved as shown in Equation (10):

$$E_{c2} = (1-y)(P_1 - M) \tag{10}$$

The average expected payoff E_c for the contractor can be expressed as shown in Equation (11):

$$E_c = zE_{c1} + (1-z)E_{c2} \tag{11}$$

And the replicator dynamic equation $G(z)$ for the contractor's decision of "supplying prefabricated construction technology" can be solved as shown in Equation (12):

$$G(z) = dz/dt = (z - z^2)[y(xL + P_2 - P_1 - abM) + M - P_1] \tag{12}$$

B. Evolutionary Stability of Developers' Decisions

The stability condition for developers' decisions is that the value of $G(y)$ is 0, and $\partial G(y)/\partial y < 0$.

By setting $G(y)$=0, we can solve for y and obtain y=0 and y=1, with $x^{*}=[(1-z)(Q_1 - P_1) - z(Q_2 - P_2)]/zJ$. If $x = x^{*}$, then $G(y) = 0$, and developers' decisions remain in an evolutionarily stable state. If $x \neq x^{*}$, then $y = 0$ and $y = 1$ are two possible stable points of the equation.

Taking the partial derivative of $G(y)$ with respect to y, we have $\partial G(y)/\partial y = (1-2y)[z(xJ + Q_2 - P_2) - (1-z)(Q_1 - P_1)]$.

When $(1-z)(Q_1 - P_1) < z(Q_2 - P_2)$ and we substitute y=0 and y=1 into $\partial G(y)/\partial y$, we have $\partial G(y)/\partial y > 0$ and $\partial G(y)/\partial y < 0$. This means that "adopting prefabricated construction technology" is an evolutionarily stable strategy for developers when $1 > x > 0 > x^{*}$.

Similarly, when $(1-z)(Q_1 - P_1) > z(Q_2 - P_2)$ and we substitute $y = 0$ and $y = 1$ into $\partial G(y)/\partial y$, we have $\partial G(y)/\partial y > 0$ and $\partial G(y)/\partial y < 0$, indicating that "adopting prefabricated construction technology" is an evolutionarily stable strategy for developers when $1 > x > x^{*} > 0$. If $1 > x^{*} > x > 0$, when we substitute y=0 and y =1 into $\partial G(y)/\partial y$, we have $\partial G(y)/\partial y < 0$ and $\partial G(y)/\partial y > 0$, showing that the decision to "adopt cast-in-place construction technology" is an evolutionarily stable strategy for developers.

C. Evolutionary Stability of Contractors' Decisions

The stability condition for contractors' decisions is that the value of $G(z)$ is 0, and $\partial G(z)/\partial z < 0$.

By setting $G(z) = 0$, we can solve for z and obtain $z = 0$ and $z = 1$, with $y^{*} = [P_1 - M]/[P_2 - (2 + ab)M + P_1 + xL]$. If $y = y^{*}$, then $G(z) = 0$, and contractors' decisions remain in an evolutionarily stable state. If $y \neq y^{*}$, then $z = 0$ and $z = 1$ are two possible stable points of the equation.

Taking the partial derivative of $G(z)$ with respect to z, we have $\partial G(z)/\partial z = (1-2z)[y(xL + P_2 - P_1 - abM) + M - P_1]$.

When we substitute z=0 and z=1 into $\partial G(z)/\partial z$, we have $\partial G(z)/\partial z > 0$ and $\partial G(z)/\partial z < 0$. This means that "supplying prefabricated construction technology" is an evolutionarily stable strategy for contractors when $1 > y > y^{*} > 0$.

Similarly, when we substitute $z = 0$ and $z = 1$ into $\partial G(z)/\partial z$, we have $\partial G(z)/\partial z < 0$ and $\partial G(z)/\partial z > 0$, indicating that "adopting cast-in-place construction technology" is an evolutionarily stable strategy for contractors when $1 > y^{*} > y > 0$.

D. Analysis on System Evolution Stability

The equilibrium points of the game among the government, developers, and contractors are determined by the strategy space of the system, which is $\{(x, y, z) \mid 0 \le x \le 1, 0 \le y \le 1, 0 \le z \le 1\}$[19]. The stability of the equilibrium points in the game system is determined by the local stability of the Jacobian matrix [20]. The Jacobian matrix of the three-player game system is denoted as F, as shown in equation (13).

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

The elements of the Jacobian matrix *F* can be calculated as shown in equations (14) to (22).

$$\frac{\partial G(x)}{\partial x} = (1-2x)yz(A_2 - J - L) \tag{14}$$

$$\frac{\partial G(x)}{\partial y} = x(1-x)z(A_2 - J - L) \tag{15}$$

$$\frac{\partial G(x)}{\partial z} = x(1-x)y(A_2 - J - L) \tag{16}$$

$$\frac{\partial G(y)}{\partial x} = y(1-y)zJ \tag{17}$$

$$\frac{\partial G(y)}{\partial y} = (1-2y)[z(xJ + Q_2 - P_2) - (1-z)(Q_1 - P_1)] \tag{18}$$

$$\frac{\partial G(y)}{\partial z} = y(1-y)(xJ + Q_2 - P_2 + Q_1 - P_1) \tag{19}$$

$$\frac{\partial G(z)}{\partial x} = z(1-z)yL \tag{20}$$

$$\frac{\partial G(z)}{\partial y} = z(1-z)[xL + P_2 - (2+ab)M + P_1] \tag{21}$$

$$\frac{\partial G(z)}{\partial z} = (1-2z)[y(xL + P_2 - P_1 - abM) + M - P_1] \tag{22}$$

The equilibrium point is the vertex of the strategy space, which is composed of *x*, *y*, and *z*. By substituting the equilibrium point into the matrix *F*, we can solve for the matrix eigenvalues, as shown in Tab. 2.

According to the Lyapunov theorem, the stability of the equilibrium point is determined by the signs of the matrix eigenvalues. If the real parts of all eigenvalues at the equilibrium point are less than 0, it is an evolutionarily stable point [21]. To determine the evolutionary stability of the equilibrium point, we will discuss the signs of each matrix eigenvalue under different conditions.

The eigenvalue λ_1 has two scenarios, referred to as scenario 1 and scenario 2. Scenario 1: $A_2 > J + L$, $\lambda_1\big|_{P_7} > 0$, $\lambda_1\big|_{P_8} < 0$; scenario 2: $A_2 < J + L$, $\lambda_1\big|_{P_7} < 0$, $\lambda_1\big|_{P_8} > 0$.

The eigenvalue λ_2 has three scenarios, referred to as scenario ①, scenario ②, and scenario ③. Scenario ①: $Q_1 - P_1 > 0, Q_2 - P_2 > 0$; scenario ② : $Q_1 - P_1 > 0, Q_2 - P_2 < 0, J + Q_2 - P_2 > 0$; scenario ③ : $Q_1 - P_1 > 0, Q_2 - P_2 < 0$, $J + Q_2 - P_2 < 0$. The signs of the matrix eigenvalue λ_2 are shown in Tab. 3.

The sign of the eigenvalue λ_3 can be classified into three scenarios, referred to as scenario I, scenario II, and scenario III.

Scenario I: $P_1 - M > 0, P_2 - (1+ab)M > 0$;

Scenario II: $P_1 - M_1 > 0, P_2 - (1+ab)M < 0,\ L + P_2 - (1+ab)M > 0$;

Scenario III: $P_1 - M_1 > 0, P_2 - M_2 < 0,\ L + P_2 - (1+ab)M < 0$

The signs of the eigenvalue λ_3 of the matrix are shown in Tab. 4.

Considering the combined eigenvalues λ_1, λ_2, and λ_3, there are 18 different scenarios to discuss regarding the strategy combination for the diffusion of prefabricated construction technology under the government intervention.

Table 2: Eigenvalues of the Jacobian Matrix

Local equilibrium points	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
$P_1(0, 0, 0)$	0	P_1-Q_1	M-P_1
$P_2(1, 0, 0)$	0	P_1-Q_1	M-P_1
$P_3(0, 1, 0)$	0	Q_1-P_1	P_2-$(1+ab)M$
$P_4(0, 0, 1)$	0	Q_2-P_2	P_1-M
$P_5(1, 1, 0)$	0	Q_1-P_1	$L+P_2$-$M(1+ab)M$

$P_6(1, 0, 1)$	0	$J+Q_2-P_2$	P_1-M
$P_7(0, 1, 1)$	A_2-J-L	P_2-Q_2	$(1+ab)M-P_2$
$P_8(1, 1, 1)$	$J+L-A_2$	P_2-Q_2-J	$(1+ab)M-P_2-L$

Table 3: The signs of Matrix Eigenvalues λ2

No.	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
Scenario ①	-	-	+	+	+	+	-	-
Scenario ②	-	-	+	-	+	+	+	-
Scenario ③	-	-	+	-	+	-	+	+

Table 4: The Signs of Matrix Eigenvalues λ3

No.	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
Scenario I	-	-	+	+	+	-	-	-
Scenario II	-	-	-	+	+	-	+	-
Scenario III	-	-	-	+	-	-	+	+

The stability analysis of the evolutionary dynamics for scenarios P_1 to P_8 under different situations is shown in Tab. 5.

According to Tab. 5, in scenario (2, ①, I), the developers' decision to "adopt prefabricated construction technology" yields greater benefits than the development cost, while the contractors' decision to "supply prefabricated construction technology" yields greater benefits than the construction cost. Both the developers and contractors actively choose prefabricated construction technology. However, the potential benefits the government can obtain from the diffusion of prefabricated construction technology are smaller than the incentive cost. Therefore, the government chooses the "no incentive" decision. As a result, the strategy (0, 1, 1) is an evolutionarily stable strategy. In scenario (1, ①, I), scenario (1, ①, II), scenario (1, ②, I), and scenario (1, ②, II), the government actively encourages the developers and contractors because it can obtain significant expected benefits from the successful diffusion of prefabricated construction technology. Under the government's incentive condition, the benefits for both the developers and contractors exceed the construction cost. Therefore, the strategy (1, 1, 1) is the evolutionarily stable strategy under these conditions.

Table 5: Scenarios of Equilibrium Point Evolutionary Stability

Scenario No.	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
1,①,I	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	ESS
1,①,II	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	ESS
1,①,III	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
1,②,I	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	ESS
1,②,II	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	ESS
1,②,III	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
1,③,I	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
1,③,II	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
1,③,III	Saddle point	Saddle point	Unstable	Unstable	Unstable	Saddle point	Unstable	Unstable
2,①,I	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	ESS	Unstable
2,①,II	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
2,①,III	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
2,②,I	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
2,②,II	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
2,②,III	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
2,③,I	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable

2,③,II	Saddle point	Saddle point	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable
2,③,III	Saddle point	Saddle point	Unstable	Unstable	Unstable	Saddle point	Unstable	Unstable

III. SIMULATION MODELLING

In this paper, the connections between different cost-benefit parameters were constructed using the VENSIM software. The replication dynamics equation from the previous text was replicated, and the causal relationships between the cost-benefit parameters were simulated, dynamically displaying the evolution process of the system. The SD flow diagram for the diffusion of prefabricated construction technology under government intervention has been constructed, as shown in Figure 1. This SD flow diagram consists of 3 state variables, 3 flow variables, 9 auxiliary variables, and 22 external initial variables.

Next, the evolutionary trends that affect the diffusion of prefabricated construction technology under different conditions were simulated by replicating the cost-benefit parameters. The simulation system was set as follows: the starting time was set to 0, the time step was set to 0.0078125, and the simulation end time was set to 100. In this section, based on Scenario (1, ②, II), the cost-benefit parameters were set as follows: $x=y=z=0.5$, $A_1=3$, $A_2=7$, $A_3=3$, $J=2.5$, $L=2.5$, $P_1=4$, $Q_1=5$, $P_2=5.5$, $Q_2=5$, $M=3$, $a=0.5$, $b=2$. Under these conditions, the evolutionary paths of different decision-makers are shown in Figure 2.

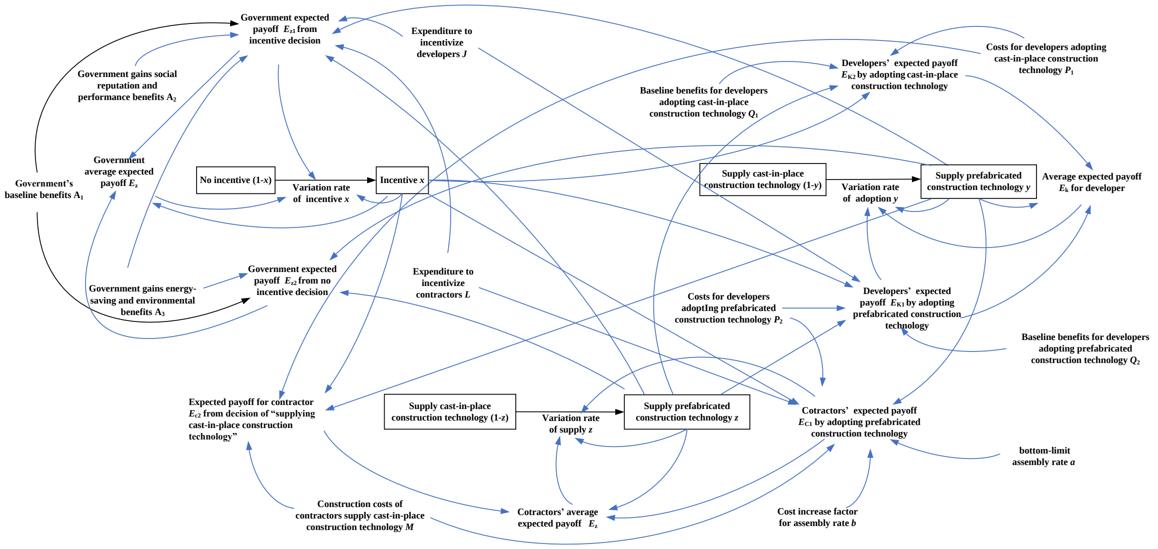

Figure 1: SD Flow Diagram of Prefabricated Construction Technology Diffusion under Government Intervention

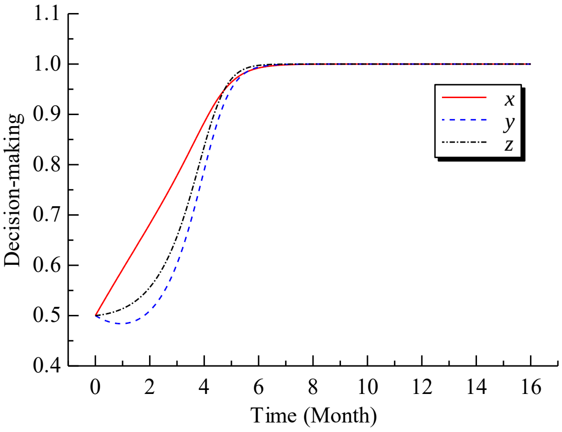

Figure 2: Evolutionary Paths of Scenario (1, ②, II)

In this section, the controlled variable method was used, which means that the values of the main cost-benefit parameters are consistent with the parameter settings in Figure 2. By changing the value of a single parameter, the impact of different cost-benefit parameters on the decisions of the parties involved was analyzed.

A. The Influence of Supply Cost on Decision-Making by All Parties

In this section, the changes in supply cost of prefabricated construction technology were characterized by adjusting the lower limit assembly rate (a) and the cost increase coefficient (b) to simulate the evolutionary paths of decision-making by all parties under different supply cost conditions.

Based on the assumed cost-benefit parameters in Figure 2, the influence of the lower limit assembly rate (a) on the decision-making behavior of the government, developers, and contractors was explored. While keeping the other cost-benefit parameters constant, the changes in the evolutionary trends of decision-making by all parties were simulated when the lower limit assembly rate was set to a = 20%, 50%, and 80%. The simulation results are shown in Figures 3 and 4.

According to the analysis of Figures.3 and 4, it can be observed that the lower limit assembly rate increases, the probability of developers and contractors adopting prefabricated construction technology decreases. This is because as the lower limit assembly rate becomes higher, the cost of supplying prefabricated construction technology increases for contractors, leading to a decrease in expected benefits. As a result, they tend to choose traditional cast-in-place construction technology. On the other hand, when the government does not provide sufficient incentives for prefabricated construction technology due to its limited diffusion, developers experience lower profits and are more inclined to adopt the cast-in-place construction technology. This indicates that appropriately reducing the lower limit assembly rate is beneficial for the diffusion of prefabricated construction technology.

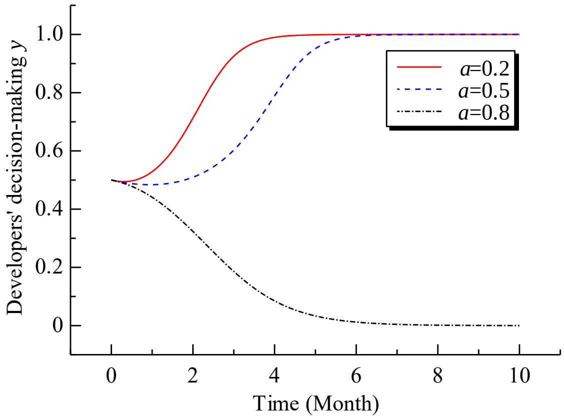

Figure 3: Influence of Bottom-Limit Assembly Rate on Developers' Decision-Making

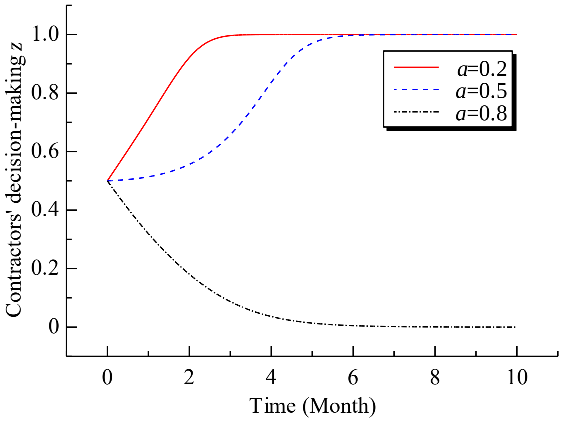

Figure 4: Influence of Bottom-Limit Assembly Rate on Contractors' Decision-Making

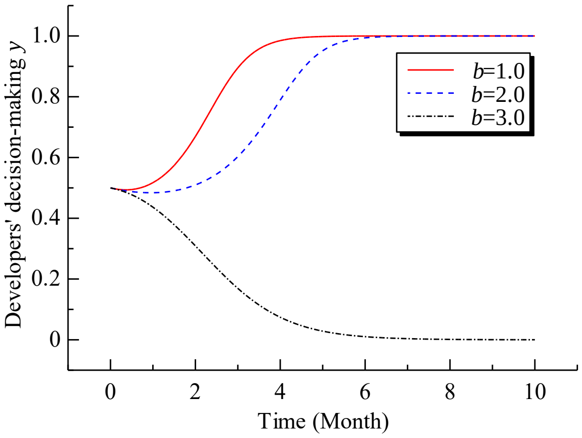

Figure 5: Influence of Cost Increase Factor on Developers' Decision-Making

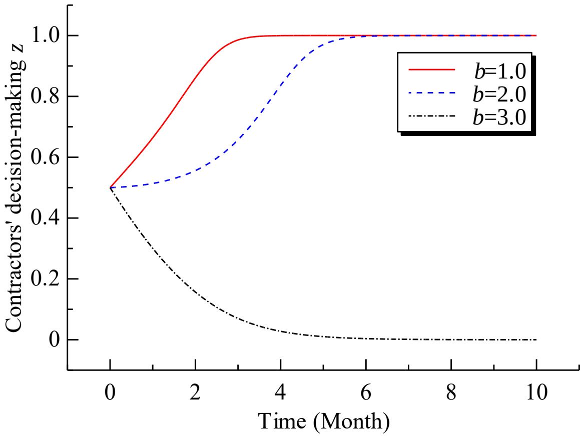

Figure 6: Influence of Cost Increase Factor on Contractors' Decision-Making

The simulated results depicting the changes in the behavior decisions of the three parties when the cost increase factor (*b*) was set to 1, 2, and 3, while keeping the profit and loss parameters consistent with Figure 2, are shown in Figures 5 and 6.

Due to fact that adjusting the cost increase coefficient *b* and the lower limit of assembly rate *a* both affect the supply cost, their effects are similar and the reasons behind them are also similar, which will not further be elaborated here.

B. Influence of Incentive Cost on Decision-Making of All Parties

Keeping the cost parameters consistent, the impact of government incentives *J* and *L* on the decision-making of developers and contractors was explored. The evolving trends of decision-making for developers and contractors were simulated separately when the developers were incentivized with costs $J = 1$, 2.5, and 4, and the contractors were incentivized with costs $L = 1$, 2.5, and 4. The changes in the decision-making trends for each party are shown in Figures 7 to 12, as depicted by the simulation results.

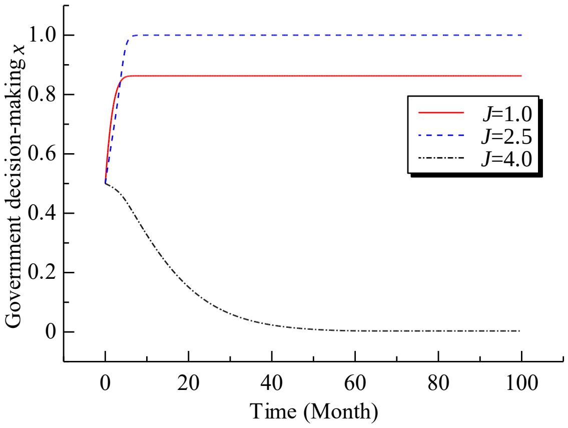

Figure 7: Influence of Cost J on Government Decision-Making

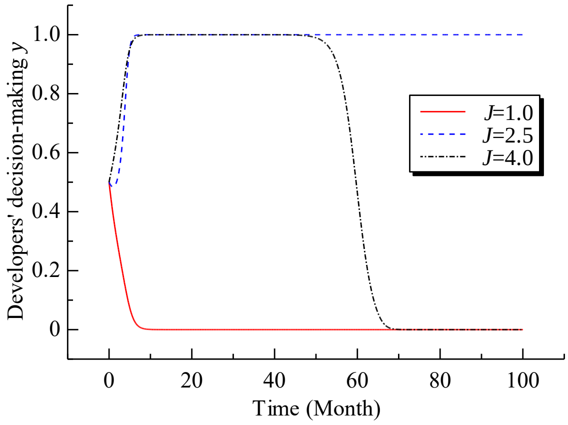

Figure 8: Influence of Cost J on Developers' Decision- Making

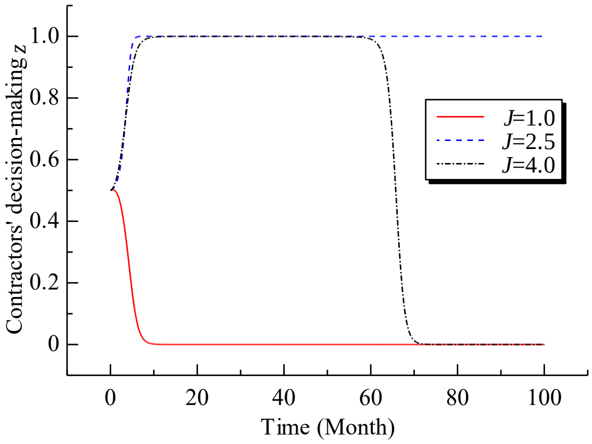

Figure 9: Influence of Cost J on Contractors' Decision-Making

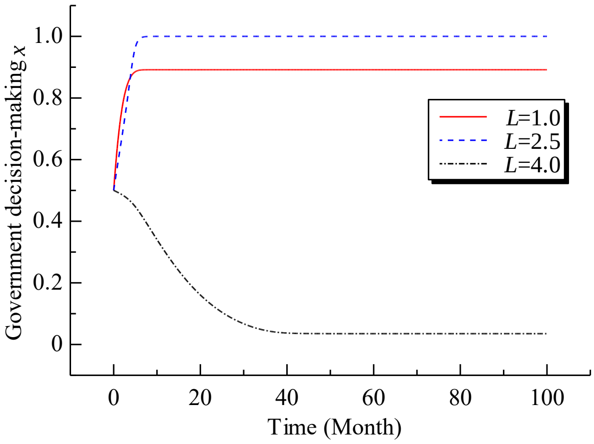

Figure 10: Influence of Cost L on Government Decision-Making

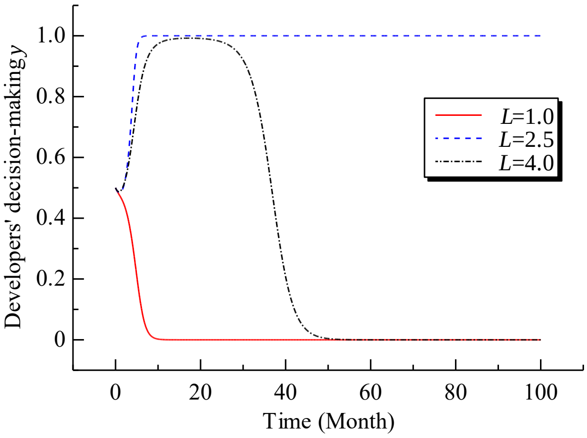

Figure 11: Influence of Cost L on Developers' Decision-Making

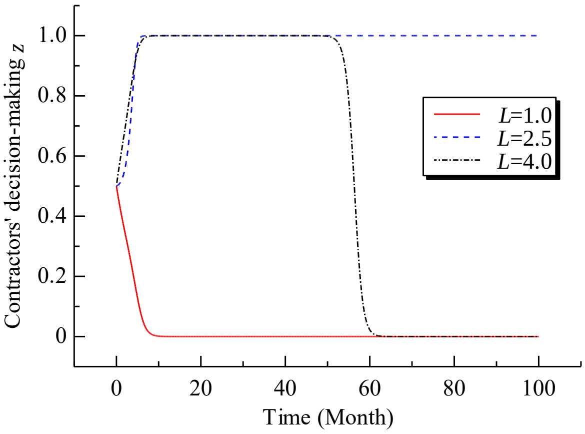

Figure 12: Influence of Cost L on Contractors' Decision-Making

The analysis of Figures 7 to 12 reveals that appropriately increasing government incentives for developers and contractors is beneficial for the diffusion of prefabricated construction technology. However, excessively high incentive costs can dampen the government's willingness to provide incentives. This is because an appropriate increase in incentives can raise the expected returns for developers and contractors, thereby facilitating the diffusion of prefabricated construction technology. However, when the government's incentive costs become too high, the government's benefits become smaller than the required costs, leading to a shift towards non-incentivized decision-making. As a result, developers and contractors experience a significant decrease in their returns after losing government support, prompting them to revert to conventional construction methods. This indicates that appropriately increasing the intensity of government incentives is advantageous for promoting the diffusion of prefabricated construction technology.

IV. CONCLUSIONS

Through constructing a three-party game model for the diffusion of prefabricated construction technology and using Vensim software for simulation, the paper explored the impact of different factors on the decisions of each party. The conclusions are as follows:

Evolutionary game theory, based on the assumption of bounded rationality, overcomes the limitations of traditional game theory. It can dynamically demonstrate the trend of decision evolution by combining it with the system dynamics software,

Reducing the cost of diffusing prefabricated construction technology is beneficial to its spread. It can be achieved by setting appropriate minimum prefabrication rates by the government or by reducing the construction cost and production cycle of prefabricated construction technology through technological innovation. By doing so, the enthusiasm of developers and contractors to adopt prefabricated construction technology can be increased, effectively promoting its diffusion.

Increasing government incentives appropriately is beneficial to the promotion of prefabricated construction technology. By increasing the level of policy support and subsidy amounts for government incentives, the benefits of developers and contractors in adopting prefabricated construction technology can be enhanced, thereby facilitating its diffusion.

Increasing the supervision and punishment appropriately. The construction companies are highly sensitive to government punishment actions, and the excessive punishment intensity will lead to fluctuations in strategy choices for both players. Therefore, it is necessary to plan dynamic reward and punishment mechanisms, to increase penalties for companies that fail to comply with standard requirements within a reasonable range.

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