Development of EPC model in Chinese public projects: evolutionary game among stakeholders

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ABSTRACT

To promote the EPC (engineering, procurement, construction) model in public projects has become a key task of China’s construction industry reform. However, the behavioral and strategic choices of stakeholders related to the EPC model will affect its stable development. We establish a tripartite evolutionary game model of government-owner-construction company, and analyze the behavioral strategies and influencing factors of these stakeholders in the development of the EPC model based on actual engineering case data. The results show that (1) there are six evolutionary stable strategies, formed from different combinations of conditions. Among them, the strategy of government incentive, owner choice, and company upgrading qualification is the most suitable for the development of the EPC model in China; (2) the relevant parameters have threshold effects, which may affect the behavioral strategies of various stakeholders. Therefore, the standards of government incentive policies must be scientific and reasonable.

1. Introduction

The traditional project delivery method (PDM) is DBB (design-bid-build) model, which is in the order of “design, bid and build”, and is known for its low efficiency and fragmentation (Love et al. 2012). A series of improved, alternative PDMs have been developed, such as construction management (CM), design-build (DB), engineering procurement and construction (EPC), and integrated project delivery (IPD). However, even in the United States, where the construction market is relatively developed, the DBB model is still dominant. The design-build project delivery market share and market size report in 2014 noted that the proportion of PDM in the U.S. construction industry that adopted DBB was 52%.

With increasingly complex construction projects and increasing numbers of subjects and disciplines (Franz et al. 2017; Mei et al. 2017), the demand for an alternative PDM is increasing, especially for government-funded public projects. Due to their long term and strict regulation, public projects in most areas can only use a single DBB model. However, with the increasing demand for sustainable and high-quality development of the construction industry, it has been put on the agenda to change the single PDM in public projects; this is particularly true in China. In 2016, the “Opinions of the Ministry of Housing and Urban-Rural Development on Further Promoting the EPC Development of Projects” stated that it is necessary to deepen the reform of the organization and implementation of construction projects as well as to promote the EPC model, that construction units and government investment projects shall give priority to the EPC model, and that prefabricated buildings should actively adopt the EPC model. In 2017, the “Opinions on Promoting the Sustainable...
and Healthy Development of the Construction Industry” pointed out that to accelerate adoption of the EPC model of construction projects is a priority of the reform and development of the construction industry. In 2019, the Ministry of Housing and Urban-Rural Development and the National Development and Reform Commission issued the “Notice on the Management Measures for EPC model of Housing Construction and Municipal Infrastructure Projects,” clearly stating that projects with clear construction content and mature technical schemes should adopt the EPC model. A series of policies have established in principle that state-owned and government-funded public projects should actively use the EPC model.

In EPC, “engineering” includes not only the specific design work but the overall planning of a project, as well as the planning and specific work of its implementation, organization, and management (Wang and Zhang 2013); “procurement” refers to professional equipment and materials; and “construction” includes, for example, installation, commissioning, and technical training. The EPC model connotes that the enterprise engaged in the general contracting of a project is entrusted to carry out the whole process or several stages of its survey, design, procurement, construction, and trial operation (completion acceptance) according to the contract. The general contractor is fully responsible for the quality, safety, construction period, and cost of the project. Depending on the scope of the contract, its types include turnkey project general contracting (turnkey), design-purchasing-construction general contracting (EPC), design-construction general contracting (DB), design-purchasing general contracting (EP), and purchasing-construction general contracting (PC) (Chen et al. 2011; Xia, Chan, and Yeung 2011).

Studies have found difficulties in the use and development of the EPC model in public projects, to mainly include legal and market restrictions (Azhar, Kang, and Ahmad 2014; Yu, Shen, and Shi 2017; Khwaja et al. 2018), which are more obvious in China.

(i) Legal restrictions. Although a series of policies have been issued to encourage the use of the EPC model in public projects, they have not been regulated by law. In China, public project owners are mostly local governments and their organizational departments. Due to the strict accountability system, public project owners are more willing to adopt a more mature DBB model to reduce the risks caused by noncompliance with laws and regulations.

(ii) Market constraints. The separate operation of design-procurement-construction in China has resulted in a small number of companies with EPC capabilities, which has caused a long-term lack of awareness of its advantages, and a series of problems, including the following: the design and construction units do not trust each other and cannot cooperate; the owner cares about the cost of the construction stage and ignores the cost of the project’s complete life cycle; the design unit charges fees in proportion to the cost and does not consider the reasonable cost of the project; and the construction unit just builds according to the drawings and does not provide professional and operable opinions on the design work.

As mentioned above, the development of the EPC model in public projects is a huge challenge for the Chinese government and construction industry. This complex system involves the interaction of stakeholders such as the government, project owners, and construction-related enterprises. The literature does not adequately discuss the decision-making behavior of core stakeholders in the development of the EPC model. How to promote this model from the perspective of stakeholder behavior synergy is the purpose of this paper. Obviously, the benefits brought by different behavioral decisions constitute the driving force for the behaviors of related parties. We propose an evolutionary game method to analyze the decision-making behavior of government, owners, and enterprises in the development of the EPC model.

The remainder of this paper is organized as follows. Section 2 discusses the literature on the research and evolution of PDM, influencing factors, and decision-making methods, and finds a lack of analysis of PDM from the perspective of the entire construction industry and stakeholders. In Section 3, we establish a government-owner-company tripartite game model based on the problems of developing the EPC model in China’s public projects, and theoretically analyze the equilibrium and stability of the strategic choices of core stakeholders. In Section 4, we simulate the strategic choices of stakeholders, and take the most suitable situation for China as an example to examine the key factors that affect the strategic choice of stakeholders. Section 5 discusses key factors affecting the behavior of stakeholders, countermeasures, and suggestions for the development of the EPC model in public projects in China. Section 6 discusses our conclusions, their limitations, and future prospects.
2. Literature review

Although the development stages and pace of evolution in the construction industry differ around the world, finding how best to encourage the evolution of PDM is a common problem in the construction industry.

2.1. Evolution and restriction of PDM

The literature shows that the evolution of the PDM is produced with the development of technology, social progress and the maturity of the construction industry, and it was a substitute for the traditional DBB model (Gordon 1994).

Under the traditional DBB model, the owner has complete control over the design and can obtain contractors with competitive prices. However, the interaction between design and construction is particularly poor, and disputes between the two parties have led to higher costs and extended construction periods. The CM model was introduced to increase the constructability of the design (Mulvey 1998). However, this did not significantly reduce the owner's management workload, and the lack of ability and experience of most owners caused the DB model of a single responsible entity to emerge. What's more, the alternative PDM has not been rapidly developed quickly enough to truly replace the mainstream status of DBB model. Kent and Becerik-Gerber (2010) pointed out that PDM has developed slowly because the construction industry is accustomed to traditional leadership methods, responsibilities, and opportunities. Azhar, Kang, and Ahmad (2014) maintained that legal, organizational, and technical issues have impeded the use of alternative PDM in public projects. Lena and Sward (2019) believed that the industry's conservative nature have limited the evolution of PDM. Guo, Li, and Yang (2016) analyzed the problems in the development of EPC in China, including lack of design ability of construction companies, insufficient financing, lack of general contracting management talent, lack of laws and supporting policies, low levels of construction markets, and the current construction enterprise qualification is unreasonable.

2.2. Influencing factors of PDM

Choosing an appropriate PDM can effectively improve project performance, and is an important issue (Zhu et al. 2020) whose influencing factors have been analyzed extensively.

Some studies rely on expert knowledge or experience to summarize these factors, which are relatively comprehensive, but lack depth. Other studies have examined the factors that influence the owner's choice of PDM in actual projects, and have screened out factors that are specific enough but not comprehensive.

Influencing factors include project scale, complexity, uncertainty, clarity of project scope, and flexibility; schedule, cost, and quality performance objectives; clear responsibility; risk control and allocation; price competition; owner's ability, experience, and willingness to participate and control; attitude toward disputes; market environment; policy and regulation; contractor capacity and quantity; and innovation (Table 1).

2.3. Decision-making method of PDM

Much research has been devoted to the development of decision-making methods to help owners choose an appropriate PDM.

Most studies have constructed multi-attribute decision-making models based on the analytic hierarchy process (AHP), considering project characteristics, owner needs, and the external environment (Cheung et al. 2001; Khalil 2002; Mahdi and Alresheid 2005; Noorza 2020). However, this does not solve the problem of ambiguous selection criteria. Some fuzzy multi-attribute decision-making models have been proposed on this basis (Ng et al. 2002; Chan 2007; Mostafavi and Karamouz 2010), and others have been based on knowledge and experience, using case-based reasoning (Luu, Ng, and Chen 2003), artificial neural networks (Chen et al. 2011), and other methods.

In developed countries with relatively mature construction industry markets, scholars stress how to choose the right PDM, and not its development from the perspective of the entire construction industry. In fact, although the development of the construction industry differs around the world, how to develop a more integrated and efficient PDM is a common issue. China is in the stage of comprehensive development of the EPC model, which is regarded as the key to the sustainable, high-quality development of the industry. Therefore, it is necessary to discuss how to effectively and scientifically develop the EPC model. We establish a tripartite evolutionary game model for government, project owners, and construction companies, and study the behavioral strategies and influencing factors of these stakeholders.

3. Methodology

3.1. Evolutionary game model

In behavioral science research, game theory has been widely used to explore the behavioral characteristics and strategies of stakeholders (Shan and Yang 2019). Traditional game theory is often used to study the strategic confrontation and competition among
stakeholders, based on the premise that participants are completely rational, but this is difficult to achieve in reality. Evolutionary game theory considers the bounded rationality of decision makers and focuses on the dynamics of strategy changes, which is helpful to analyze decision behavior in multi-player game situations (Chu et al. 2020). It has become a common tool in social governance and enterprise management. In this study, the development of an EPC model depends on the strategic decisions of stakeholders, which makes evolutionary game theory appropriate, as it can provide mathematical solutions for different behavioral strategy situations (Du et al. 2020).

Evolutionary game theory combines game theory with analysis methods of evolutionary dynamics, which is closer to the behavioral patterns of realistic decision-making activities. It can more accurately reflect the dynamic equilibrium of the game behavior of bounded rational groups. The key to the evolutionary game model is to determine the mechanism adjustment of learning and strategy. When the rationality of stakeholders is relatively low or group decision-making is involved, the “replicated dynamic” mechanism of biological evolution can be used to simulate their learning and dynamic adjustment process (Shan and Yang 2019).

The most general continuous form of replicated dynamic equations is the differential equation,

$$\frac{dn_i}{dt} = n_i(\varphi_i(n) - \varphi(n)) \quad (1)$$

where $n_i$ is the proportion of strategy $i$ in stakeholder $n$, $\varphi_i(n)$ is the expected payoff of strategy $i$ in stakeholder $n$, and $\varphi(n)$ is the average payoff of stakeholder $n$. If $\frac{dn_i}{dt}$ reaches a stable state in iteration, then strategy $i$ will be called an evolutionary stable strategy (ESS).

This research promotes the development of the EPC model in public projects in China. Its steps are shown in Figure 1. We describe the behavioral strategies of key stakeholders, and define the benefits and costs of different behavioral strategies of the government, owners, and construction companies through research hypotheses. On this basis, the perceived benefits of each game player and the replicated dynamic equation are obtained. We analyze the equilibrium strategy and stability of the evolutionary game, and

### Table 1. Influencing factors.

| Influencing factor | Statement |
|--------------------|-----------|
| Scale              | Project scale [1][7]; Project size [2][4][5][8][10]; |
| Complexity         | Project complexity [1]; Complexity [2][7][8][10][12][13]; |
| Uncertainty        | Environmental uncertainty [1]; Site conditions [2]; Uncertain site conditions [4]; Project technical uncertainty [5]; |
| Clarity of scope   | Level of scope definition [2]; Clarity of scope [4]; Ability to clearly state end user’s requirements [6]; Ability to define project scope [7]; Capitalizing on well-defined scope [9]; Scope change [12]; |
| Flexibility        | Project flexibility [2][4]; Flexibility in quality control [4]; Flexibility to changes [5]; Flexibility [7][13]; |
| Schedule performance objective | Time requirement [1]; Criticality of schedule [4]; Schedule performance objective [5]; Delivery speed [7]; Schedule [8][10][12]; Control time growth [9]; Assurance of shortest schedule [9]; Reduced schedule [11]; Speed [13]; |
| Cost performance objective | Cost requirement [1]; Lower total project cost [1][4]; Cost performance objective [5]; Owner’s requirement for low maintenance cost [6]; Cost certainty [7]; Cost [8][10][12]; Life cycle costs [8][10]; Control of cost growth [9]; Assurance of lowest cost [9]; Facilitation of early cost estimate [9]; Early cost establishment [11]; Cost savings [11]; |
| Quality performance objective | Quality requirement [1]; Quality performance objective [5]; Quality performance [7]; Enhancement of quality [11]; |
| Clear responsibility | Single entity responsible for design and construction [11]; Clarity of responsibility [5]; Responsibility [6]; Staffing required [8][10]; Point of responsibility [13]; |
| Risk control and allocation | Ability to undertake risks [1]; Client’s risk attitude [5]; Owner’s willingness to take risks [7]; Risk control and allocation [5]; Risk allocation [8][10]; Risk management [8][10]; Risk allocation [8][10]; Reduction of risk or transfer of risk to contractor [9]; Risk [12]; Risk avoidance [13]; |
| Price competition   | Price competition [5][13]; Competition [8][10]; |
| Owner’s ability and experience | Management ability [1]; staff capability [2][8][10]; Agency inexperience [4][8][10]; Client’s technical ability [5]; |
| Owner’s willingness to participate and control | Owner’s willingness to control project [5]; Owner’s willingness to control design [6]; Owner’s willingness to be involved [7]; Owner’s controlling role [9]; Owner’s involvement [9]; Build involvement in process [11]; |
| Attitude toward disputes | Attitude toward disputes [1]; Likelihood of disputes and claims [2]; Disputes [7]; |
| Market environment  | Management [1]; Marketplace conditions [2]; Market competitiveness [3]; Unfavorable marketplace conditions [4]; Economic environment [5]; External environment [7]; |
| Policy and regulation | Policy and regulation [1][5]; Federal/state/local laws [2][8][10]; External approval [12]; Political impacts [3]; Regulatory feasibility [7]; |
| Contractor capacity and quantity | Contractor’s number [1]; Contractor’s capability [7]; Potential contractor’s ability [5]; Qualifications and past performance of designer and builder [11]; Technology availability [7]; Potential contractor’s market reputation [1]; Potential contractor’s credibility [5]; Market competitiveness [7]; Potential contractor’s service level [1]; |
| Innovation          | Innovative [11]; Innovation [2][4][11]; Efficient coordination of project complexity or innovation [9]; |

[1] Zhu et al. (2020); [2] Demetrapooulo, O’Brien, and Khawaja (2020); [3] Liu et al. (2019); [4] Khawaja et al. (2018); [5] Qiang et al. (2015); [6] Liu et al. (2015); [7] Chen et al. (2011); [8] Touran et al. (2011); [9] Mostafavi and Karamouz (2010); [10] Touran et al. (2009); [11] Puerto, Gransberg, and Shane (2008); [12] Mafakheri et al. (2007); [13] Chan (2007).
theoretically analyze the conditions for the equilibrium point to become a stable point. Through simulation and empirical analysis, we determine the relationship between the parameters through a real case, verify the stability strategy of the evolutionary game system, and determine the key factors that affect the behavioral strategy of the government, owners, and enterprises.

### 3.2. Problem formulation

In China, the government encourages public project owners to adopt the EPC model, which has changed the single-PDM situation of public projects. However, due to the limited rationality of stakeholders, the choice and development of the EPC model still face major obstacles.

For public project owners, PDMs have different costs and performance. The EPC model generally uses a fixed-price contract, which includes the cost of the general contractor (Wang and Zhang 2013). Therefore, the engineering contract cost of the EPC model usually exceeds that of the DBB model. This discourages owners from adopting the EPC model. However, the EPC model greatly reduces the time and investment of the owner in engineering organization and management-related work, and can achieve faster delivery (Zhu et al. 2020). If these are important to public project owners and can generate actual economic value, then the attractiveness of the EPC model to owners will increase.

Because China’s construction industry implements a qualification access system, if a construction company wants to undertake an EPC project, it usually must have all the qualifications to undertake its survey, design, and construction. As China has long implemented the separate operation of design-procurement-construction links, the number of companies with EPC qualifications is small (Yang et al. 2017). For most construction companies, to upgrade their qualifications to enable them to undertake EPC projects may require the establishment of new companies or the acquisition of another, which entails a significant investment. They can also contract EPC projects by forming an EPC consortium with other companies. This requires no additional investment, but reduces the owner’s trust in the company’s capabilities.

For the Chinese government, the development of the EPC model is conducive to achieving the high-quality and sustainable development of the construction industry. Therefore, promotion of the EPC model will have good external benefits. As discussed above, to implement the EPC model requires additional expenditure for project owners or construction companies, who lack motivation. The government can consider an incentive mechanism, such as positive incentives (economic subsidies, tax incentives, and credit incentives) or negative incentives (penalties and additional taxes) (Yang et al. 2019). At the same time, to implement incentive mechanisms has a certain regulatory cost.

### 3.3. Assumptions

We make the following assumptions for the analysis of the stakeholder cooperation mechanism of China’s development of the EPC model:

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**Figure 1.** Research framework.
(1) The game model involves three stakeholders with limited rationality: the government, project owners, and construction companies. Since the players all seek the maximum expected benefits under the premise of information asymmetry, they cannot choose the optimal strategy in only one game.

(2) There are two main PDMs for public projects in China: DBB and EPC. Therefore, the owner’s strategic space is (choose EPC, choose DBB), where \( y \) and \( 1 - y \) are the probabilities that the owner chooses EPC and DBB, respectively. The strategic space for a construction company is (upgrade qualifications, do not upgrade qualifications), with respective probabilities \( z \) and \( 1 - z \). The government’s strategic space is (incentive, no incentive), with respective probabilities \( x \) and \( 1 - x \).

(3) \( G \) represents the social benefits of engineering projects constructed using the DBB model, and \( B \) represents the increased social benefits of the EPC model compared to the DBB model. \( D1 \) and \( D2 \) represent the government subsidies to EPC project owners and construction companies, respectively. \( C \) represents the regulatory cost incurred by the government in encouraging the EPC model, and \( T \) is the punishment for projects that choose the DBB model under the incentive strategy.

(4) For the owner, the sum of the expenses paid to construct the project, including production, organization, and management cost, is called the project transaction cost. Expenses paid to companies such as for survey, design, and construction at the contract price can be regarded as production costs. All operating and management expenditures other than production costs can be regarded as organizational management costs. For the same project, using the DBB model, the contract price of the project is \( P1 \), the organization and management cost is \( Q1 \), and the owner’s benefit is \( R1 \); using the EPC model, the contract price of the project is \( P2 \), the organization and management cost is \( Q2 \), and the owner’s benefit is \( R2 \), where \( P1 \leq P2 \), \( Q1 \geq Q2 \).

(5) The difference between DBB and EPC projects is that a DBB project is completed by the survey, design, and construction companies, while these are independently completed by an EPC company for an EPC project. For a DBB project, the proportion of professionally qualified construction companies undertaking the business part is \( y \), and the profit rate is \( a \). For an EPC project, the additional cost to establish and operate an EPC consortium is \( M1 \), the cost of upgrading a qualified construction company to EPC qualification is \( M2 \), and the project profit rate of the EPC company is \( \beta \), where \( M1 \leq M2 \).

According to the above assumptions, the payment matrix of the tripartite game is shown in Table 2.

### 3.4. Evolutionary stable analysis

#### 3.4.1. Replicated dynamic equation

The expected return of the government when it chooses the incentive strategy is

\[
U_x = y[z(G + B - C - D1 - D2) + (1 - z)(G + B - C - D1)] + (1 - y)[z(G - C + T) + (1 - z)(G - C + T)].
\]

(2)

The expected return of the government when it chooses the no-incentive strategy is

\[
U_{1-x} = y[z(G + B) + (1 - z)(G + B)] + (1 - y)[zG + (1 - z)G].
\]

(3)

Accordingly, the average expected return of the government is

\[
\bar{U}_x = xU_{1-x} + (1 - x)U_{1-x}.
\]

(4)

Taking the proportion of the incentive strategy as an example, the replicated dynamic equation of the government can be expressed as

### Table 2. Payment matrix of tripartite game.

| Government | Incentive (x) | No incentive (1-x) |  | Incentive (x) | No incentive (1-x) |
|------------|---------------|--------------------|---|---------------|-------------------|
| Choose EPC (y) | \( G + B - C - D1 - D2 \) | \( G - C + T \) | \( yP1a - M1 \) | \( G + B - C - D1 \) | \( G - C + T \) | \( yP1a - M1 \) |
| Choose DBB (1-y) | \( G - C + T \) | \( yP1a - M1 \) | \( G + B \) | \( G - C + T \) | \( yP1a - M1 \) | \( G + B \) |
| Choose EPC (y) | \( G + B - C - D1 - D2 \) | \( G - C + T \) | \( yP1a - M1 \) | \( G + B - C - D1 \) | \( G - C + T \) | \( yP1a - M1 \) |
| Choose DBB (1-y) | \( G - C + T \) | \( yP1a - M1 \) | \( G + B \) | \( G - C + T \) | \( yP1a - M1 \) | \( G + B \) |
\[
\frac{dx}{dt} = x(U_x - U_x) = x(1 - x)(U_x - U_{1-x}) \\
= x(1 - x)(-C + TyD_1 - yD_2). \quad (5)
\]

The expressions \( U_x \) and \( U_{1-x} \) represent the expected return of the owner when choosing the strategies of “choose EPC” and “choose DBB,” respectively, which can be expressed as

\[
U_y = x[z(R_2 - P_2 - Q_2 + D_1) + (1 - z)(R_2 - P_2 - Q_2 + D_1)] \\
+ (1 - x)[z(R_2 - P_2 - Q_2) + (1 - z)(R_2 - P_2 - Q_2)]. \quad (6)
\]

\[
U_{1-y} = x[z(R_1 - P_1 - Q_1 - T) + (1 - z)(R_1 - P_1 - Q_1 - T)] \\
+ (1 - x)[z(R_1 - P_1 - Q_1) + (1 - z)(R_1 - P_1 - Q_1)]. \quad (7)
\]

and the average expected return of the owner is

\[
\bar{U}_y = yU_{1-y} + (1 - y)U_{1-y} \quad (8)
\]

Accordingly, the replicated dynamic equation of the owner choosing the EPC strategy can be expressed as

\[
\frac{dy}{dt} = y(U_y - \bar{U}_y) = y(1 - y)(U_y - U_{1-y}) \\
= y(1 - y)(R_2 - R_1 - P_2 - Q_2 + xD_1 + P_1 + Q_1 + xT). \quad (9)
\]

The expressions \( U_x \) and \( U_{1-x} \) represent the expected return of the construction company when choosing the strategies of “upgrading qualifications” and “not upgrading qualifications,” respectively, and can be expressed as

\[
U_y = x[y(P_2 \beta - M_2 + D_2) + (1 - y)(yP_1 \alpha - M_2)] \\
+ (1 - x)[y(P_2 \beta - M_2) + (1 - y)(yP_1 \alpha - M_2)]. \quad (10)
\]

\[
U_{1-y} = x[y(P_1 \alpha - M_1) + (1 - y)(yP_1 \alpha)] \\
+ (1 - x)[y(P_1 \alpha - M_1) + (1 - y)(yP_1 \alpha)]. \quad (11)
\]

The average expected return of the construction company is

\[
\bar{U}_y = zU_{1-y} + (1 - z)U_{1-y} \quad (12)
\]

The replicated dynamic equation of the construction company choosing the strategy of upgrading qualifications can be expressed as

\[
\frac{dz}{dt} = z(U_x - \bar{U}_x) = z(1 - z)(U_x - U_{1-x}) \\
= z(1 - z)[xD_2 - M_2 + y(P_2 \beta - yP_1 + M_1)]. \quad (13)
\]

Due to the limited rationality of the government, owner, and construction company, it is difficult for them to make the best choice in a game. Therefore, Equations (5), (9), and (13) can be considered to indicate an evolutionary process, forming a tripartite replicated dynamic system. Over iterations, the government, owner, and construction company may find strategies to maximize their benefits, and eventually develop an ESS.

### 3.4.2. Equilibrium solution

As mentioned above, the game is constantly evolving. Hence the probabilities of any strategies chosen by the government, owner, and construction company are time-dependent, and can be expressed as \( x(t), y(t), z(t) \in [0, 1] \), respectively. Thus the solution domain \( O \) of the replicated dynamic system, consisting of Equations (5), (9), and (13), is \( [0, 1] \times [0, 1] \times [0, 1] \).

Obviously, when all the dynamic equations are set to 0, then the entire dynamic system will tend to be stable, and the government, owner, and construction company are able to choose the optimal strategy. Therefore, the equilibrium points of the tripartite game model can be calculated as

\[
\begin{align*}
F_1 & = \frac{dy}{dt} = x(1 - x)(-C + TyD_1 - yD_2) = 0 \\
F_2 & = \frac{dy}{dt} = y(1 - y)(R_2 - R_1 - P_2 - Q_2 + xD_1 + P_1 + Q_1 + xT) = 0 \\
F_3 & = \frac{dy}{dt} = z(1 - z)[xyD_2 - M_2 + y(P_2 \beta - yP_1 + M_1)] = 0
\end{align*}
\]

(14)

The equilibrium points can be identified easily by solving Equation (14). Among these are eight special equilibrium points: \( D_1(0, 0, 0) \), \( D_2(1, 0, 0) \), \( D_3(0, 1, 0) \), \( D_4(0, 0, 1) \), \( D_5(1, 1, 0) \), \( D_6(1, 1, 1) \), \( D_7(0, 1, 1) \), \( D_8(1, 1, 1) \). All players adopt a pure strategy in each of these equilibrium points, which constitute the boundary of the domain \( O \).

In addition, an equilibrium point of hybrid strategy (D9) may exist when

\[
\begin{align*}
(-C + TyD_1 - yD_2) & = 0 \\
(R_2 - R_1 - P_2 - Q_2 + xD_1 + P_1 + Q_1 + xT) & = 0 \\
xyD_2 - M_2 + y(P_2 \beta - yP_1 + M_1) & = 0
\end{align*}
\]

(15)

We derive

\[
\begin{align*}
x_9 & = \frac{N_1 - N_2 - P_1 - Q_1}{M_2} \\
y_9 & = \frac{M_2}{x_9 + y_9 + z_9} \\
z_9 & = \frac{M_9}{T - C - yD_2}
\end{align*}
\]

(16)

If \( 0 \leq x_9, y_9, z_9 \leq 1 \), i.e., if D9 falls within the domain \( O \), then D9 is an equilibrium point, and otherwise it will be rejected.

### 3.5. Asymptotic stability

The equilibrium points of the system are described in Section 3.4. However, it is unclear whether the equilibrium points derived from the replicated dynamic equations constitute an ESS. Only when the equilibrium points simultaneously satisfy both a strict Nash equilibrium and a pure strategy Nash equilibrium will they turn into an asymptotically stable equilibrium point, called a “sink.” Consequently, since D9 is a hybrid strategy, it may not be considered a sink. Moreover, by analyzing the eigenvalues of the Jacobian matrix of the system, its asymptotic stability at the equilibrium point can be found. Among them, that all
the eigenvalues of the Jacobian matrix are negative is a necessary and sufficient condition for the asymptotic stability of the system. Thus the Jacobian matrix of the tripartite dynamic game can be calculated as

\[
J = \begin{bmatrix}
\frac{\partial x}{\partial x} & \frac{\partial y}{\partial x} & \frac{\partial z}{\partial x} \\
\frac{\partial x}{\partial y} & \frac{\partial y}{\partial y} & \frac{\partial z}{\partial y} \\
\frac{\partial x}{\partial z} & \frac{\partial y}{\partial z} & \frac{\partial z}{\partial z}
\end{bmatrix} = \begin{bmatrix}
F_{11} & F_{12} & F_{13} \\
F_{21} & F_{22} & F_{23} \\
F_{31} & F_{32} & F_{33}
\end{bmatrix}
\]  

(17)

where

\[
F_{11} = (1 - 2x)(-C + T - yD_1 - yzD_2),
\]

\[
F_{12} = -x(1 - x)D_1 - xz(1 - x)D_2,F_{13} = -xy(1 - x)D_2,
\]

\[
F_{21} = y(1 - y)(D_1 + T),
\]

\[
F_{22} = (1 - 2y)(R_2 - R_1 - P_2 - Q_2 + P_1 + Q_1 + xD_1 + xT),F_{23} = 0, F_{31} = z(1 - y)D_2,
\]

\[
F_{32} = z(1 - z)xD_2 + z(1 - z)(P_2\beta - ayP_1 - M_1),
\]

\[
F_{33} = (1 - 2z)(xyD_2 - M_2 + y(P_2\beta - ayP_1 + M_1)).
\]

Then, by including the eight equilibrium points \(D_1 \sim D_8\) in Equation (17), the Jacobian matrices corresponding to all equilibria can be calculated.

For, \(D_1(0,0,0)\), the Jacobian matrix is

\[
J_1 = \begin{bmatrix}
-\lambda & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(18)

The eigenvalues of \(J_1\) are \(\lambda_{11} = -\lambda, \lambda_{12} = R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1), \lambda_{13} = -M_2\)

. According to the judgmental criterion, when \(\lambda_{11} < 0, \lambda_{12} < 0, \lambda_{13} < 0\), then \(D_1(0,0,0)\) is the sink, and otherwise it is a saddle point.

Similarly, the Jacobian matrix at \(D_2(1,0,0)\) is

\[
J_2 = \begin{bmatrix}
-C - T & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(19)

The eigenvalues of \(J_2\) are \(\lambda_{21} = -C - T, \lambda_{22} = R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) + D_1 + T, \lambda_{23} = -M_2\)

, where \(\lambda_{21} = -\lambda_{11}\) shows that equilibria \(D_1(0,0,0)\) and \(D_2(1,0,0)\) cannot be the sink simultaneously. When \(\lambda_{21} < 0, \lambda_{22} < 0, \lambda_{23} < 0\), then \(D_2(1,0,0)\) is the sink.

The Jacobian matrix at \(D_3(0,1,0)\) is

\[
J_3 = \begin{bmatrix}
-C + T & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(20)

The eigenvalues of \(J_3\) are \(\lambda_{31} = -C + T - D_1, \lambda_{32} = [R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1)], \lambda_{33} = -M_2 + P_2\beta - ayP_1 + M_1\)

, where \(\lambda_{32} = \lambda_{33} = -\lambda_{33}\) shows that equilibria \(D_1(0,0,0)\) and \(D_3(0,1,0)\), as well as \(D_3(0,1,0)\) and \(D_3(0,1,1)\), cannot be the sink simultaneously. \(D_3(0,1,0)\) is the sink only if \(\lambda_{31} < 0, \lambda_{32} < 0, \lambda_{33} < 0\).

The Jacobian matrix at \(D_4(0,0,1)\) is

\[
J_4 = \begin{bmatrix}
-C + T & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(21)

The eigenvalues of \(J_4\) are \(\lambda_{41} = -C + T, \lambda_{42} = R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1), \lambda_{43} = -M_2\)

. \(D_4(0,0,1)\) is the ESS only if \(\lambda_{41} < 0, \lambda_{42} < 0, \lambda_{43} < 0\), where \(\lambda_{43} = -\lambda_{41} = -\lambda_{42} = \lambda_{43}\)

shows that equilibria \(D_4(0,0,0)\) and \(D_4(1,0,0)\) are not the sink when \(D_4(0,0,1)\) and \(D_4(1,0,1)\) are the sink. According to the assumptions in Section 3.3, it can be found that \(M_2\) represents the cost of transforming a traditional professional construction company to an EPC construction company, and it should be greater than 0.

As a result, \(D_4(0,0,1)\), is not asymptotically stable. Similarly, the Jacobian matrices of \(D_6(1,0,1)\) have positive eigenvalues, and therefore, all are saddle points.

The Jacobian matrix at \(D_5(1,1,0)\) is

\[
J_5 = \begin{bmatrix}
-C + T + D_1 & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(22)

The eigenvalues of \(J_5\) are \(\lambda_{51} = -C + T + D_1, \lambda_{52} = [R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) + D_1 + T], \lambda_{53} = D_2 - M_2 + P_2\beta - ayP_1 + M_1\)

, \(D_5(1,1,0)\) is a sink only if \(\lambda_{51} < 0, \lambda_{52} < 0, \lambda_{53} < 0\). When \(\lambda_{52} = -\lambda_{53}\)

, the equilibria \(D_5(1,1,0)\) and \(D_6(1,1,1)\) are not the sink when \(D_2(1,0,0)\) is the sink.

The Jacobian matrix at \(D_6(1,0,1)\) is

\[
J_6 = \begin{bmatrix}
-C + T & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(23)

As mentioned above, \(D_6(1,0,1)\) is a saddle point.

The Jacobian matrix at \(D_7(1,0,1)\) is

\[
J_7 = \begin{bmatrix}
-C + T + D_1 - D_2\lambda & 0 & 0 \\
0 & -\lambda & 0 \\
0 & 0 & -\lambda
\end{bmatrix}
\]  

(24)

The eigenvalues of \(J_7\) are \(\lambda_{71} = -C + T - D_1 - D_2, \lambda_{72} = [R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1)], \lambda_{73} = M_2 - P_2\beta - ayP_1 - M_1\)

, \(D_7(0,1,1)\) is the sink only if \(\lambda_{71} < 0, \lambda_{72} < 0, \lambda_{73} < 0\). When \(\lambda_{73} = -\lambda_{72}\)

, equilibria \(D_7(0,1,1)\) and \(D_3(0,1,0)\) cannot be the sink simultaneously.

The Jacobian matrix at \(D_8(1,1,1)\) is...
Table 3. Conditions of stability at equilibrium points.

| Equilibrium point | Condition of ESS |
|-------------------|------------------|
| \( D_1(0, 0, 0) \) | \( T - C < 0; R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) < 0; M_2 < 0 \) |
| \( D_2(1, 0, 0) \) | \( C - T < 0; R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) + D_1 + T < 0; M_2 < 0 \) |
| \( D_3(1, 0, 1) \) | \( C + T + D_1 < 0; M_2 + \beta P_2 - \alpha y P_1 + M_1 < 0 \) |
| \( D_4(1, 1, 1) \) | \( C - T + D_1 + D_2 < 0; M_2 - P_2 \beta + \alpha y P_1 - M_1 < 0 \) |

\[
J_8 = \begin{bmatrix}
-C + T + D_1 + D_2 & 0 & 0 \\
0 & \frac{R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) + D_1 + T}{D_1} & 0 \\
0 & 0 & -D_2 + M_2 - \frac{P_2 \beta + \alpha y P_1 - M_1}{\beta + \alpha y P_1 - M_1}
\end{bmatrix}
\]

The eigenvalues of \( J_8 \) are \( \lambda_{b1} = C - T + D_1 + D_2 \), \( \lambda_{b2} = \frac{R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) + D_1 + T}{D_1} \), \( \lambda_{b3} = -D_2 + M_2 - \frac{P_2 \beta + \alpha y P_1 - M_1}{\beta + \alpha y P_1 - M_1} \). \( D_8(1, 1, 1) \) is the sink only if \( \lambda_{b1} < 0, \lambda_{b2} < 0, \lambda_{b3} < 0 \).

Based on the above analysis, the conditions of the six equilibrium points that may be the sink are illustrated in Table 3, and are of practical significance.

(1) \( D_1(0, 0, 0) \) implies that to upgrade the professional qualifications of construction companies to EPC qualification has a certain cost. For the owner to choose the DBB model has a smaller transaction cost than to choose the EPC model. The government only has a punishment mechanism for EPC supervision, and the cost of punishment for owners who choose the DBB model is less than the supervision cost paid by the government. As a result, none of the players will choose to cooperate.

(2) \( D_2(1, 0, 0) \) implies that to upgrade construction companies to EPC qualification has a certain cost. The government’s subsidies for owners who choose the EPC model and penalties for those who choose the DBB model have not changed the status quo that the EPC model has higher transaction costs than the DBB model, so the owners will not choose the EPC model, and construction companies will not upgrade.

(1) \( D_2(1, 0, 0) \) implies that for construction companies, the benefits of obtaining EPC projects by upgrading their qualifications are less than those obtained by forming EPC consortiums, so they will not upgrade their qualifications. The government’s penalty for owners who do not choose the EPC model is less than the sum of the government’s subsidies to owners who choose the EPC model and the associated supervision costs. However, absent government subsidies, the transaction cost of EPC model chosen by the owner is less than that of DBB model, so the owner will choose EPC model for bidding, and thus does not need government subsidies.

(2) \( D_2(1, 1, 0) \) implies that the government’s penalty for owners who do not choose the EPC model is less than the sum of the government’s subsidies to those who choose the EPC model and the associated supervision costs. After government subsidies and penalties, the transaction cost of EPC model is less than that of DBB model, so the owner will choose to cooperate with the government. However, government subsidies are insufficient to compensate for lost project income after upgrading the qualification and forming a consortium, so construction companies will not choose to upgrade the qualification.

(3) \( D_7(0, 1, 1) \) implies that under the condition of no government incentive, the transaction cost of the EPC model chosen by owners is lower than that of the DBB model, and construction companies can profit more by upgrading their qualifications than by forming an EPC consortium. Therefore, owners will choose EPC for bidding, and construction companies will choose to upgrade their qualifications.

(1) \( D_8(1, 1, 1) \) implies that the government’s penalty for owners who choose the DBB model is greater than the sum of its subsidies to owners and companies plus the associated supervision costs. After subsidies and penalties, the transaction costs of owners choosing the EPC model are less than those of the DBB model, and construction companies can profit more by upgrading their qualifications than by forming an EPC consortium. So, all players will choose to cooperate.

4. Simulation and empirical analysis

Through the above theoretical analysis, six evolutionary stable strategies are identified, which can be obtained when corresponding conditions are satisfied. Among them, \( D_1(0, 0, 0) \) indicates that the government does not implement incentive measures, the owners do not choose the EPC model, and the construction enterprises do not upgrade their qualifications. \( D_2(1, 0, 0) \) indicates that the government implements incentive measures, the owners choose the EPC model, and construction enterprises do not upgrade their
qualifications. \( D_3(0, 1, 0) \) indicates that the government does not implement incentive measures, the owners choose the EPC model, and construction enterprises do not upgrade their qualifications. \( D_3(1, 1, 0) \) indicates that the government implements incentive measures, owners choose the EPC model, and construction enterprises do not upgrade their qualifications. \( D_7(0, 1, 1) \) indicates that the government does not implement incentive measures, the owners choose the EPC model, and construction enterprises upgrade their qualifications. \( D_5(1, 1, 1) \) indicates that the government implements incentive measures, owners choose the EPC model, and construction enterprises upgrade their qualifications. To intuitively observe the evolutionary trajectories of the stakeholders and their sensitivity to parameters requires the simulation of their strategies, which we did using MATLAB.

### 4.1. Simulation data

Before the simulation, we investigated the data of a real project in Qingdao and determined the relationships between certain parameters.

A residential development project, the total construction area is 80,000 m². The project owner adopts the DBB model. For the owner, the project’s survey and design costs are each 1.6 million, and the construction contract price is 208 million. The total fees for agent construction, supervision, and process consulting incurred in project management are 11.81 million. We consulted some professionals with more than 15 years of industry experience, including Senior Consultant, Senior Engineer, Senior Official, Senior Director, Department Manager and Professor. Table 4 shows their affiliations. It is estimated that if the project adopts the EPC model, the possible production generation (contract price) and organization and management costs will be 219.7 million and 5.1 million, respectively.

If the project bidding is in the EPC model, and the construction company wants to build the project, it can form a consortium with qualified survey and design companies at a cost of 1 million. It will cost a construction company about 1.5 to 15 million to upgrade its qualifications, depending on the level. According to the average profit level of China’s construction industry in 2020, the net profit rates of project survey, design, and construction are 2%, 3.5%, and 3.5%, respectively, and the profit rate of EPC companies is 5%. The cost paid by the owner to the construction enterprise accounts for about 98% of the total project investment.

Based on the above information, we determined the following parameters: \( P_1 = 21, P_2 = 22, Q_1 = 1.2, Q_2 = 0.5, M_1 = 0.1, M_2 = 0.25, a = 3.5\%, \beta = 5\%, \gamma = 98\%\).

The investment and construction of this project can bring 10 million in social benefits to the government (e.g., providing jobs, promoting economic development). Compared to the DBB model, EPC can improve the performance level of the project and the satisfaction of all stakeholders, generating social benefits assumed to be worth 5 million. To promote the development of EPC, the government will supervise the behavior of owners and companies, at a cost of 15 million. The subsidy for owners adopting the EPC model for bidding is 5 million, and the subsidy for construction companies to upgrade their qualifications is 5 million. The penalty for owners not adopting the EPC model for bidding is 10 million. We preliminarily determine the following parameters: \( G = 1, B = 0.5, C = 0.15, T = 0.1, D_1 = 0.05, D_2 = 0.05\).

### 4.2. Simulation results

To make the equilibrium points in Table 3 meet the conditions of the evolutionary stable strategy, we assume the parameters of six cases, as shown in Figures 2–7. Regardless of the initial strategy, the equilibrium points are \( D_1(0, 0, 0), D_2(1, 0, 0), D_3(0, 1, 0), D_5(1, 1, 0) \), and \( D_7(0, 1, 1), D_6(1, 1, 1) \) is the ESS.

### 4.3. Sensitivity analysis

As mentioned above, the promotion and development of the EPC model is important to the reform of China’s construction industry. The government hopes to promote the model’s acceptance by owners and architectural enterprises through active measures. Thus \( D_6(1, 1, 1) \) is the stable state to be achieved by the tripartite game system. A sensitivity analysis of the involved parameters will enhance the perception of the research problem. We changed initial parameter values,
observed their influence on ESS, and sorted out the crucial factors for \( D_1(1, 1, 1) \). It should be noted that when we analyze the sensitivity of a parameter, its value should meet the conditions in Table 2, while the values of the other parameters are as in scenario VI (Figure 7). Assume that the initial policy probabilities of the government, owners, and construction companies are 0.5. The sensitivity of their strategic choices to parameters is as follows.

As shown in Figure 8, as the cost of supervision increases, the government’s ability to subsidize projects and construction companies declines, resulting in a decrease in government incentives, which in turn...
Figure 5. Evolution of government, owner, and company at $D_t(1.1,0)$, Scenario IV: $C = 0.15$, $T = 0.3$, $D1 = 0.05$, $D2 = 0.05$, $R1 = 25$, $R2 = 25.1$, $P1 = 21$, $P2 = 22$, $Q1 = 1.2$, $Q2 = 0.5$, $M1 = 0.1$, $M2 = 1.5$, $\alpha = 3.5\%$, $\beta = 5\%$, $\gamma = 0.98$.

Figure 6. Evolution of government, owner, and company at $D_t(0.1,1)$, Scenario V: $C = 0.15$, $T = 0.1$, $D1 = 0.05$, $D2 = 0.05$, $R1 = 25$, $R2 = 25.5$, $P1 = 21$, $P2 = 22$, $Q1 = 1.2$, $Q2 = 0.5$, $M1 = 0.1$, $M2 = 0.25$, $\alpha = 3.5\%$, $\beta = 5\%$, $\gamma = 0.98$.

Figure 7. Evolution of government, owner, and company at $D_t(1.1,1)$, Scenario VI: $C = 0.15$, $T = 0.3$, $D1 = 0.05$, $D2 = 0.05$, $R1 = 25$, $R2 = 25.1$, $P1 = 21$, $P2 = 22$, $Q1 = 1.2$, $Q2 = 0.5$, $M1 = 0.1$, $M2 = 0.25$, $\alpha = 3.5\%$, $\beta = 5\%$, $\gamma = 0.98$.

Figure 8. Sensitivity analysis of government, owners, and companies to $C$. 
reduces the owners’ willingness to adopt the EPC model for bidding, and construction companies’ willingness to upgrade to EPC qualifications. The cost of supervision generally has the greatest impact on the government’s strategy, while the impact on construction companies is small. Moreover, the lower the government’s regulatory cost, the faster its incentive strategy will converge. As the cost of supervision increases, the strategies of the government and owners will fluctuate, and the system cannot form a stable strategy. When the cost of supervision further increases to a certain extent, the ESS changes from (1, 1, 1) to (0, 0, 0).

As shown in Figure 9, the probability that the owner adopts the EPC model for bidding increases with the punishment. At this time, the construction company will choose to upgrade to the qualifications required by EPC. Punishment measures generally have the greatest impact on the owner’s behavior strategy, and the greater the punishment, the faster that strategy will converge. However, when the penalty for owners who adopt the DBB model for bidding is too small, and the owners think that the DBB model for bidding can still obtain higher returns, the owners will not use the EPC model for bidding, and accordingly, construction companies will not seek to upgrade qualifications. At this time, the ESS changes from (1, 1, 1) to (1, 0, 0).

As shown in Figure 10, subsidies for EPC projects have the greatest impact on the government’s strategies, followed by the owners. Generally speaking, owners’ willingness to adopt the EPC model for bidding will increase as with government subsidies for EPC projects. With the increase in subsidies, the convergence of the government strategy slows down, and the convergence of the owner strategy becomes faster. However, when the subsidy intensity reaches a certain level, the social benefits brought by EPC will not be obvious, thereby reducing the government’s willingness to subsidize the project, and affecting the owner’s strategy. The system will gradually enter shocks and cannot form a stable ESS, so the stability point will not change.

As shown in Figure 11, the willingness of construction companies to upgrade to EPC qualifications will increase with government subsidies. With an increase in subsidies, the convergence of the government and owner’s strategies generally slow down, and the convergence of the company becomes faster. However, incentives to
subsidize construction companies seem to have little impact on their strategies, and they will actually have a greater impact on the strategies of the government and owner, possibly because the effect of the subsidy is not obvious, and the government will continue to increase the subsidy intensity. When the subsidy intensity reaches a certain level, the social benefits will not be obvious, which will reduce the government’s subsidy intensity to construction companies, leading to the lack of enthusiasm of construction companies to upgrade to EPC qualification. The insufficient number of EPC construction companies further reduces the likelihood that the owners will use the EPC model for bidding. In order to support the development of EPC, the government will need to continue to increase subsidies; then, the willingness of construction enterprises to upgrade the EPC qualification will increase, and the number of owners choosing EPC will also increase. When the subsidies reach the level that the government can afford again, the willingness of construction enterprises to upgrade the EPC qualification will decrease with the reduction of government subsidies . . . and the whole system is oscillating. Therefore, the system still has only one stable point (1, 1, 1).

As shown in Figure 12, as the benefits of EPC projects increase, owners’ willingness to adopt the EPC model for bidding increases, which leads to greater willingness of construction companies to upgrade to EPC qualifications, thereby reducing the possibility of government supervision. The benefits of the EPC model generally have the greatest impact on owners, followed by construction companies. Moreover, the greater the benefits the EPC model brings to owners, the faster the convergence of the corresponding strategies of the owners and construction companies, and the slower the convergence of government strategies. When the profit of the EPC model decreases to a certain extent, the stable point changes from (1, 1, 1) to (1, 0, 0).

As shown in Figure 13, when the EPC model is adopted, an owner facing a higher contract price and management cost is less willing to use it for bidding, and construction companies are less willing to upgrade to EPC qualifications, thereby increasing the possibility of supervision. The contract price and management cost of the EPC model generally have the greatest impact on the owner’s strategy, followed by construction companies. Moreover, the smaller the
contract price and management cost of the EPC model, the faster the convergence of the strategies of owners and construction companies, and the slower the convergence of the government’s strategies. To a certain extent, when the EPC model construction contract price and management cost are large, owners are unwilling to choose the EPC model for bidding, which affects the strategy of construction companies. At this time, the system stable point changes from (1, 1, 1) to (1, 0, 0).

As shown in Figure 14, the cost of upgrading EPC qualifications has the greatest impact on construction companies. As this cost increases, the willingness of companies to transform decreases. Moreover, the greater the cost of upgrading qualifications, the slower the strategies of construction companies will converge. When this cost increases to a certain level, the stability point changes from (1, 1, 1) to (1, 1, 0), indicating that construction companies are more willing to undertake EPC projects by forming a consortium.

As shown in Figure 15, the profit rate of EPC projects has the greatest impact on the behavioral strategies of construction companies, and as this increase, so does the willingness of companies to upgrade EPC qualifications. Moreover, the greater the profit rate of EPC
projects, the greater the convergence rate of corporate strategies. However, when the profit rate is reduced to a certain level, the stable point changes from \((1, 1, 1)\) to \((1, 1, 0)\).

5. Discussion

5.1. Key influencing factors

The above sensitivity analysis shows that every parameter involved in the system may be a key influencing factor, which depends on the evolutionary stable state of stakeholders in the system. Among them, \(C\), \(D1\), \(D2\), and \(T\) are the key parameters that affect the government strategy; \(T\), \(R2\), \(P2\), \(Q2\), \(D1\), \(D2\), and \(C\) will affect the owner’s strategy; and \(M2\), \(\beta\), \(R2\), \(P2\), and \(Q2\), are the key parameters that affect corporate strategy. Once the key parameters change the stable conditions at \((1, 1, 1)\), the strategies of the stakeholders in the system will change. Figure 16 describes the evolving trend and the key influencing parameters. This gives us the inspiration that the key parameter settings must be reasonable. An inappropriate incentive mechanism will destroy the cooperative relationship between stakeholders, and will play no useful role. Therefore, the introduction of government subsidies and punishment standards must be scientific.

(1) For the government, the cost of supervision necessary to implement incentives is the most critical factor in its behavioral strategies because, although the demonstration effect and social benefits produced by EPC projects are the fundamental driving force for the government to implement incentive policies, it is difficult to directly quantify economic value for such positive external social benefits. Therefore, the cost of supervision highly affects the government. If the cost of supervision is low, then the government is certainly willing to obtain higher social benefits at a lower cost. However, too high a cost of supervision will directly affect or even change the government’s strategic choice. Therefore, in the early stage of the development of China’s EPC model, to seek ways to reduce supervision costs is the key to influencing the government’s implementation of incentive policies.

(2) For owners, although punishment measures are a better incentive than subsidies, the Chinese government is more inclined to induce rather than to introduce compulsory institutional changes. We do not recommend strict or severe punishment for owners who do not adopt the EPC model. Research also shows that the practice of substituting one model for another is not worth promoting. Although the EPC model will produce good benefits, not all projects show such performance. According to the above results, the benefits of EPC projects are the second most important factor in the strategic choice of owners. Research shows that the benefits of the EPC model include good communication and sharing of information, fewer disputes with better resolution, a shorter construction period, transfer of risks, and better investment efficiency. Many of these benefits cannot be quantified and are easily ignored by owners in decision-making. Therefore, to enable owners to correctly recognize this value is the key to effectively motivating them to choose the EPC model.

(3) For companies, it is not difficult to find that the cost of upgrading to EPC qualification is the key to their decision-making choice. If the EPC model is to be well promoted and developed, there must be a group of excellent EPC companies. However, there are relatively few such companies in China. According to interviews with industry insiders, the acquisition and maintenance of qualifications currently has a large cost, and it is difficult for many small and medium-sized companies to maintain the required technical personnel, office space, and equipment. Therefore, it is necessary to create a good market environment and lower the entry barriers for EPC construction companies.

6. Conclusion

The EPC model has been widely adopted in the world and is important for the high-quality development of China’s construction industry. However, the evolution of the EPC model is complex, and it involves multiple stakeholders. We considered how to promote the development of the EPC model in China’s public projects as a research problem, and established a tripartite game model of government-owner-construction enterprise from the perspective of stakeholders in its development. The results support the following conclusions.

(1) Among the eight equilibrium points obtained by the tripartite game model are six possible stable points: \(D1(0,0,0), D2(1,0,0), D3(0,1,0), D4(1,1,0), D5(0,1,1), D6(1,1,1)\). However, the stability of a stakeholder behavioral strategy depends on a combination of conditions. When a combination of specific conditions is met (TAB), no matter the initial strategy, the government, owners, and construction enterprises will change their strategies through constant imitation and learning, and eventually evolve into a stable strategy. In this paper, according to the development vision of the Chinese EPC model, the ideal situation is that \(D4(1,1,1)\) becomes the stable point of the tripartite game system. That is, when the Chinese government implements incentives, the standards of relevant rewards and fines should
meet a combination of conditions to effectively promote the development of the EPC model:

\[ C - T + D_1 + D_2 < 0; \quad -[R_2 - P_2 - Q_2 - (R_1 - P_1 - Q_1) + D_1 + T] < 0; \quad -D_2 + M_2 - P_3 \beta + ayP_1 - M_1 < 0. \]

(2) From the sensitivity analysis, it can be seen that the supervision cost of implementing incentives has an important impact on the behavioral strategy of the government, which should pay attention to reducing the supervision cost when designing incentive schemes. The government’s punishments and the benefits of the EPC model have an important impact on the behavior of owners. A penalty is an effective strategy, but it is more ideal to convince owners of the value brought by the EPC model, which will incentivize them to choose it. The cost required to upgrade to EPC qualification has an important impact on the behavioral strategies of construction enterprises. The government is committed to reducing the market access threshold and costs of the EPC model, which will be conducive to its development.

This study contributes to both the theory and practice of stakeholder decision-making behaviors for the development of the EPC model. A tripartite evolutionary game model is theoretically established to better study the behavioral strategies of stakeholders in the construction industry. We have identified the key factors that influence their behavior in the development of the EPC model, and provided research hypotheses for future empirical studies. Our results emphasize the role of government incentive strategies to promote the development of the EPC model, and provide a theoretical basis for the government to formulate reasonable punishment and reward measures.

This study has several limitations. We cannot validate our conclusion that the government can promote the development of the EPC model in public projects through incentives, although it is consistent with most studies. This is because, at the national level, the Chinese government’s policies are mainly exhortations, and there are no economic incentives. However, to our surprise, with the continuous development of the EPC model, Chinese provinces are starting to introduce economic incentives, such as the “General Contracting Management Measures for Housing Construction and Municipal Infrastructure Projects” issued by Shandong Province on 13 July 2020. However, the effects of policies are not immediately apparent, and it takes time to evaluate them. We will continue to statistically verify their effectiveness. The decision-making behavior of stakeholders in this study is based on maximizing economic benefits, which may not represent behavior in all scenarios. In reality, decision-making may be based on other principles, such as social responsibility and public interest, which should be considered in future research. The tripartite game model constructed in this paper can aid in the analysis of key factors of PDM development in different countries. However, the research object is specific to China and ignores differences from development levels of the construction industry in other countries. The research conclusion can serve as a reference for developing countries or those with an underdeveloped construction industry, but cannot be used directly.

A successful EPC project must have a good benefit and risk distribution mechanism to maximize the synergy of stakeholders. The current EPC model is in the early stage in China. Although there is policy support, the associated management system, methods, and social credit system are not yet perfected. This will have an impact on the behavioral evaluation and decision-making of various stakeholders. It provides a direction for the in-depth study of the influencing factors and mechanisms of the EPC model development in the future.

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