

Research Article

Evolutionary Game Analysis of the Supervision Behavior for Public-Private Partnership Projects with Public Participation

Congdong Li, Xiaoli Li, and Yu Wang

School of Management, Jinan University, Guangzhou 510632, China

Correspondence should be addressed to Xiaoli Li; lx463653159@126.com

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The public can directly or indirectly participate in the PPP (public-private partnership) projects and then has an impact on the project profit and public or private behavior. To explore the influence of the public participation of the PPP projects supervision behavior, this paper analyzes the mutual evolutionary regularity of the private sector and government supervision department and the influence of public participation level on public and private behavior based on evolutionary game theory. The results show that the supervision strategy is not chosen when the supervision cost of government supervision department is greater than the supervision benefit; it can make private sector consciously provide the high-quality public products/services with the improvement of public participation level. Therefore, the government should reduce the cost of public participation and improve the public participation level and influence through the application of the Internet, big data, and other advanced technologies, in order to restrain the behavior of the private sector and improve the supervision efficiency.

1. Introduction

In recent years, the public-private partnership (PPP) is widely used in power supply [1], water supply [2], sewage and garbage disposal [3, 4], traffic [5, 6], pipes [7], and other public infrastructure construction fields and has become the main way of governments to provide public service [8, 9]. Public-private partnership refers to a cooperative relationship formed between government and private organizations, in order to build infrastructure projects or provide some public goods and services [10]. The PPP classifies the rights and obligations of both sides through “contract constraint mechanism,” to ensure the smooth completion of cooperation and eventually to make all parties achieve more advantageous results than the expected solo engagement. Why is the PPP mode so popular? Scholars think that when it is used correctly, the PPP mode not only can improve the infrastructure supply efficiency, save the total cost, and share the risk, but also can alleviate the problem of insufficient fund of public sector [8, 11]. But these are built under the premise that the private sector can provide high-quality

public products/services. However, if the private sector provides low-quality public products/services to obtain higher profits through reducing maintenance cost and ignoring environmental protection, this will seriously damage the public interests and cause bad social influence [12]. Therefore, the effective supervision of the government is indispensable. Nevertheless, with the rapid development of PPP mode, the number of PPP projects increases greatly, making the supervision more challenging than ever, and supervision costs continue to rise. For example, the public sector realizes the supervision of PPP/PFI project mainly through signing a contract with the third-party organization in Britain. The data showed that 17 major government departments spent £1 billion–£1.3 billion on the consulting and temporary workers from 2014 to 2015, bringing heavy burden to the government departments [13]. Therefore, how to reduce the supervision costs and improve the supervision efficiency is the important topic that government departments have to face. The ultimate goal of the PPP projects is to provide high-quality low-cost public services for the public, and the public opposition is often one of the important factors of the PPP projects failure,

so the public participation plays an important role in the smooth operation of the PPP projects [14–17]. More and more attention is paid to the public participation. Governments ask for the public opinions through various ways, to let the public actively participate in project operation process, and effectively influence and supervise the behavior of the private sector, improving the level of public services [18, 19]. Then does the public participation have an effect on the behaviors of the public and private parties in the process of the PPP projects supervision? And how can we formulate the reasonable supervision strategy with the public participation and improve the supervision efficiency of the government departments?

The aim of this paper is, therefore, to analyze the mutual evolution regularity of the private sector and government supervision department and the influence of public participation level of public and private behavior through the evolutionary game theory, to explore how to formulate the reasonable supervision strategy, and to improve the supervision efficiency with the public participation.

This paper is structured as follows. Section 2 reviews the theory regarding PPP and supervision. Section 3 is to build the evolutionary game model with the public participation and analyze the stability of evolutionary strategy. Section 4 is to verify the effectiveness of the model results through the numerical simulation analysis. Section 5 is the conclusions of the paper.

2. Literature Review

Generally, a PPP contract will be signed between the government and private sector and usually will consist of planning design, building, operation, and transfer of assets by the private sector [20]. Typically, all risks in the project are shared and allocated to the two sectors [21]. Therefore, the government can transform some risks to the private partner that is most able to manage them [22]. For example, demand risk, technical risk, and financial risk are taken by the private sector, while political risk and legal risk are undertaken by the government [23]. In this way, there will be an incentive for the private partner to provide services innovatively and the government will also manage the project professionally [24, 25]. However, because of the complexity of the project and the conflict of interests, the private sector may not comply with the contract all along. El-Gohary et al. thought that the concerns rose when the asset was owned by the private sector that held the mindset of profit making [26]. For instance, they may minimize operating costs to improve return and lower demand risk. Al-Saadi and Abdou proved that proper legal and regulatory framework, risk allocation, and sharing were the critical success factors for PPPs [21]. Consequently, appropriate regulation or supervision is needed [27]. The supervision gives early warning of any possible risks which may threaten the project and takes actions to deal with them [8].

Supervision of PPP projects mainly includes the project plan achieving the value for money (VFM), admittance supervision of franchisee qualification screening, and performance supervision avoiding low public services level, low

operational efficiency, market failure, and other problems [28]. Now researches on the supervision problem of PPP projects focus on the importance of project supervision and supervision mechanism design. Decorla-Souza et al. [29] believed that the government supervision level, legal system, and policies had an important effect on the successful implementation of PPP projects. Empirical studies of Yun et al. [30] and Panayides et al. [31] showed that the institutional factors as regulatory quality, market competitiveness, and contract enforcement had significant impact on the success of PPPs. Sabry [32] found that regulatory quality and effective bureaucracy had a positive effect on the performance of PPPs. Koo et al. [33] thought that the participation of the private sector would cause principal-agent problems, which affected the service efficiency, while the effective supervision of the government was a powerful means to reduce the opportunistic behavior of the private sector. However, these literatures mainly focused on the relationship between the government supervision level and project operational performance and demonstrated the importance of project supervision, and there were few researches about the supervision mechanism and strategy. Therefore, some scholars have carried on the further research on how to design the reasonable supervision mechanism. Efremov [34] and Manacorda et al. [35] studied the construction of the supervisory framework of PPP projects from the point of laws and regulations. But they concentrated on the qualitative research. In terms of the quantitative research, He and Fu [36] built the incentive model of the private sector on the premise of public products/service quality and realized the supervision of the service quality and efficiency of private sector to maximize the social welfare level. Greco [37] built the motivation and supervision model based on the principal-agent theory and studied how the government should choose the reasonable motivation and supervision level. However, the above literature ignored the relationship between the public participation and the PPP projects supervision. In fact, the public participation of the decision-making and operation of the PPP projects is a main way to really reflect social needs and public will. And it is crucial for the smooth implementation of the project [38]. For example, for the project paid by the public, the public can affect the benefits of a project through buying other services (e.g., for the subway project, the public can choose bus or drive on their own to replace the subway) in the presence of competition [39]. In addition, the public can influence the operational efficiency of the project through participating in the PPP projects decision-making [16], and these will have impact on the behavior of the private sector. Therefore, it is necessary to carry out the further research of the supervision problem of PPP projects with the public participation, to analyze how to formulate the reasonable supervision strategy with the public participation.

On the other hand, considering that the private sector and government supervision department are individuals with bounded rationality in the actual implementation process of the PPP projects because of information asymmetry, the dynamic change of environment, and the limitation of people's thought, the PPP projects supervision is a game process of continuous learning and dynamic evolution.

Therefore, on the basis of the above researches, based on evolutionary game theory, this paper studies the evolutionary track of supervision behavior of the PPP projects with the public participation and analyzes the influence of the public participation level on the behavior of private sector and government supervision department, thereby providing theoretical references for the establishment of supervision strategy.

3. Evolutionary Game Model and the Stability Analysis of the Evolution Strategy with the Public Participation

3.1. Evolutionary Game Model with the Public Participation.

Assuming that the private sector has two strategy choices, probability x means providing high-quality public products/services and probability $1 - x$ means providing low-quality public products/services, where the cost of providing high-quality public products/services is C_H and the cost of providing low-quality public products/services is C_L ; R_0 means fixed income that can be realized (such as the lowest income promised by the government, etc.); λ ($0 \leq \lambda \leq 1$) means the participation level of the public, and the increased additional income and cost when the private sector provides high-quality public products/services to meet the real needs of the public as much as possible are λR_1 and C_S , respectively; λR_2 means the additional loss suffered by the private sector when it provides low-quality public products/services with the public participation. Government supervision department chooses the probability y to supervise the private sector or chooses probability $1 - y$ not to supervise. When choosing the supervision strategy, the government supervision department can obtain income R_g (including incentive subsidies to the subordinate departments of superior departments and the recognition of the government supervision department by the public), and the cost that it needs to pay is C_g . When the private sector provides low-quality public products/services which is discovered by government supervision department, the corresponding punishment is F_s . Meanwhile when the private sector provides low-quality public products/services, government supervision department chooses not to supervise (it is assumed here that the higher the public participation level is, the higher the discovered probability is when the private sector and government supervision department get out of line), and the punishment that the government supervision department deserves is F_g .

According to the above assumption, when the private sector provides high-quality public products/services and government supervision department chooses supervision strategy, the income of the private sector is $R_0 - C_H + \lambda R_1 - C_S$ and the income of government supervision department is $R_g - C_g$. When the private sector provides high-quality public products/services and government supervision department chooses nonsupervision strategy, the income of the private sector is $R_0 - C_H + \lambda R_1 - C_S$ and the income of government supervision department is 0. When the private sector provides low-quality public products/services and government supervision department chooses supervision strategy,

the income of the private sector is $R_0 - C_L - \lambda R_2 - F_s$, and the income of the government supervision department is $R_g - C_g$. When the private sector provides low-quality public products/services and government supervision department chooses nonsupervision strategy, the income of the private sector is $R_0 - C_L - \lambda(R_2 + F_s)$ and the income of government supervision department is $-\lambda F_g$. It would seem that the game payoff matrix of private sector and government supervision department is showed in Table 1.

According to the game matrix (Table 1), the expected revenue of the private sector choosing to provide high-quality public products/services can be obtained as

$$E_x = y(R_0 - C_H + \lambda R_1 - C_S) + (1 - y)(R_0 - C_H + \lambda R_1 - C_S). \quad (1)$$

The expected revenue of the private sector choosing to provide low-quality public products/services is

$$E_{1-x} = y(R_0 - C_L - \lambda R_2 - F_s) + (1 - y)[R_0 - C_L - \lambda(R_2 + F_s)]. \quad (2)$$

The average expected revenue of the private sector is

$$\bar{E} = xE_x + (1 - x)E_{1-x}. \quad (3)$$

Thus, the replicator dynamic equation of the private sector is

$$\frac{dx}{dt} = x(1 - x) \{ [\lambda(R_1 + R_2 + F_s) - C_H - C_S + C_L] + y(1 - \lambda)F_s \}. \quad (4)$$

Similarly, the replicator dynamic equation of the government supervision department is

$$\frac{dy}{dt} = y(1 - y)(R_g - C_g + \lambda F_g - x\lambda F_g). \quad (5)$$

Therefore, the strategy evolution of the private sector and government supervision department can be described by the differential equation system made of (4) and (5) in the PPP mode. The stable point of the system is analyzed, and five equilibrium points, $P_1(0, 0)$, $P_2(0, 1)$, $P_3(1, 0)$, $P_4(1, 1)$, and $F(x^*, y^*)$, are obtained, and

$$x^* = \frac{R_g - C_g + \lambda F_g}{\lambda F_g}, \quad (6)$$

$$y^* = \frac{C_H + C_S - C_L - \lambda(R_1 + R_2 + F_s)}{(1 - \lambda)F_s}.$$

Based on literature [40], Jacobian matrix of the differential equation system made of (4) and (5) is

TABLE 1: Game payoff matrix of private sector and government supervision department with the public participation.

Private sector	Government supervision department	
	Supervising (y)	Not supervising ($1 - y$)
Providing high-quality public products/services (x)	$R_0 - C_H + \lambda R_1 - C_S, R_g - C_g$	$R_0 - C_H + \lambda R_1 - C_S, 0$
Providing low-quality public products/services ($1 - x$)	$R_0 - C_L - \lambda R_2 - F_s, R_g - C_g$	$R_0 - C_L - \lambda(R_2 + F_s), -\lambda F_g$

$$J = \begin{bmatrix} (1 - 2x) \{ [\lambda (R_1 + R_2 + F_s) - C_H - C_S + C_L] + y(1 - \lambda) F_s \} & x(1 - x)(1 - \lambda) F_s \\ -y(1 - y) \lambda F_g & (1 - 2y)(R_g - C_g + \lambda F_g - x \lambda F_g) \end{bmatrix}. \quad (7)$$

The determinant of Jacobian matrix is $\det J$:

$$\begin{aligned} \det J = & (1 - 2x) \{ [\lambda (R_1 + R_2 + F_s) - C_H - C_S + C_L] \\ & + y(1 - \lambda) F_s \} \cdot (1 - 2y) (R_g - C_g + \lambda F_g - x \lambda F_g) \\ & + x(1 - x)(1 - \lambda) F_s \cdot y(1 - y) \lambda F_g. \end{aligned} \quad (8)$$

The trace of Jacobian matrix is $\text{tr } J$:

$$\begin{aligned} \text{tr } J = & (1 - 2x) \{ [\lambda (R_1 + R_2 + F_s) - C_H - C_S + C_L] \\ & + y(1 - \lambda) F_s \} + (1 - 2y) (R_g - C_g + \lambda F_g - x \lambda F_g). \end{aligned} \quad (9)$$

3.2. Stability Analysis of the Evolution Strategy with the Public Participation

Case 1. When $C_g > R_g$, $0 < \lambda < \min((C_H + C_S - C_L)/(R_1 + R_2 + F_s), (C_g - R_g)/F_g)$, the supervision cost of government supervision department is greater than the supervision benefit, and the expected punishment when choosing nonsupervision strategy is less than the loss during the supervision due to the low participation level of the public. Meanwhile the loss suffered by the private sector when choosing to provide low-quality public products/services is less than the increased cost when providing high-quality public products/services. At this point, the system is eventually evolved to provide low-quality public products/services by the private sector and choose nonsupervision strategy by the government supervision department. $P_1(0, 0)$ is the only stable point of the system, as shown in Table 2.

Case 2. When $C_g > R_g$, $\max((C_g - R_g)/F_g, (C_H + C_S - C_L - F_s)/(R_1 + R_2)) < \lambda < (C_H + C_S - C_L)/(R_1 + R_2 + F_s)$, the supervision cost of the government supervision department is still greater than the supervision benefit, and the expected punishment when choosing nonsupervision strategy is greater than the loss during the supervision, but the obtained benefit when the private sector provides high-quality public products/services is less than the increased cost, so the strategy choice of both parties is uncertain, and the system has no stable point, as shown in Table 3.

Case 3. When $C_g > R_g$, $\max((C_g - R_g)/F_g, (C_H + C_S - C_L - F_s)/(R_1 + R_2), (C_H + C_S - C_L)/(R_1 + R_2 + F_s)) <$

$\lambda < 1$, the public participation level has reached a certain level, which has a significant impact on the income of the private sector, making the obtained benefit when the private sector provides high-quality public products/services more than the increased cost. But the supervision cost of government supervision department is still greater than the supervision benefit, and the expected punishment when choosing nonsupervision strategy is less than the loss during the supervision. Therefore, the system is eventually evolved to provide high-quality public product/service by the private sector and still choose nonsupervision strategy by the government supervision department. $P_3(1, 0)$ is the only stable point of the system, as shown in Table 4.

Case 4. When $R_g > C_g$, $(C_H + C_S - C_L - F_s)/(R_1 + R_2) < \lambda < 1$, the public participation level has reached a certain level, which has a significant impact on the income of the private sector, making the obtained benefit when the private sector provides high-quality public products/services greater than the increased cost. The supervision benefit of government supervision department is greater than the supervision cost. Therefore, the system is eventually evolved to provide high-quality public products/services by the private sector and choose supervision strategy by the government supervision department. $P_4(1, 1)$ is the only stable point of the system, as shown in Table 5.

4. Numerical Analysis

This section will explore the influence of the public participation level, participation cost, and others on the PPP projects supervision process further through the numerical analysis. According to the above assumption, the parameters are selected as follows: $R_1 = 100$, $R_2 = 120$, $R_g = 12$, $F_g = 40$, $F_s = 80$, $C_H = 70$, and $C_L = 20$.

- (1) It can be seen from Figure 1 that when $C_g > R_g$, with the increase of λ , the system evolves gradually from point $P_1(0, 0)$ to point $P_3(1, 0)$. That is, when the supervision cost is greater than the supervision benefit, the government supervision department will choose nonsupervision strategy. Moreover, due to the low participation level of the public at first ($\lambda < 0.4$), the loss suffered by the private sector when choosing

TABLE 2: Local stability analysis of Case 1.

Balance point	tr J	det J	Local stability
$P_1(0, 0)$	-	+	ESS
$P_2(0, 1)$	\pm	-	Saddle point
$P_3(1, 0)$	\pm	-	Saddle point
$P_4(1, 1)$	+	+	Instability point
$F(x^*, y^*)$	0	\pm	Saddle point

TABLE 3: Local stability analysis of Case 2.

Balance point	tr J	det J	Local stability
$P_1(0, 0)$	\pm	-	Saddle point
$P_2(0, 1)$	\pm	-	Saddle point
$P_3(1, 0)$	\pm	-	Saddle point
$P_4(1, 1)$	\pm	-	Saddle point
$F(x^*, y^*)$	0	\pm	Saddle point

TABLE 4: Local stability analysis of Case 3.

Balance point	tr J	det J	Local stability
$P_1(0, 0)$	+	+	Instability point
$P_2(0, 1)$	\pm	-	Saddle point
$P_3(1, 0)$	-	+	ESS
$P_4(1, 1)$	\pm	-	Saddle point
$F(x^*, y^*)$	0	\pm	Saddle point

to provide low-quality public products/services is less than the increased cost when providing high-quality public products/services; thus providing low-quality public products/services is the best choice. While, with the improvement of the public participation level ($\lambda \geq 0.4$), its influence on the benefit of the private sector increases, the loss when providing low-quality public products/services will be heavy. For example, the public will turn to another one if they have choices. Therefore, it can make the private sector consciously provide the high-quality public products/services to some extent.

- (2) It can be concluded from Figure 2 that the cost of encouraging the public to actively participate in the operation process of PPP projects also has impact on the choice of the private sector. This is because understanding the real demand of the public and meeting the public preference need to take certain time and economic costs. As the cost C_S reduces constantly, the private sector will actively choose the strategy of providing the high-quality public products/services. Therefore, compared with purely relying on improving the punishment on the irregularities of the private sector, the government also can reduce the cost of public participation, relieve the information asymmetry of supplier and demander of the project, and improve the service efficiency through adopting the advanced technologies (such as the Internet and big data related technologies).

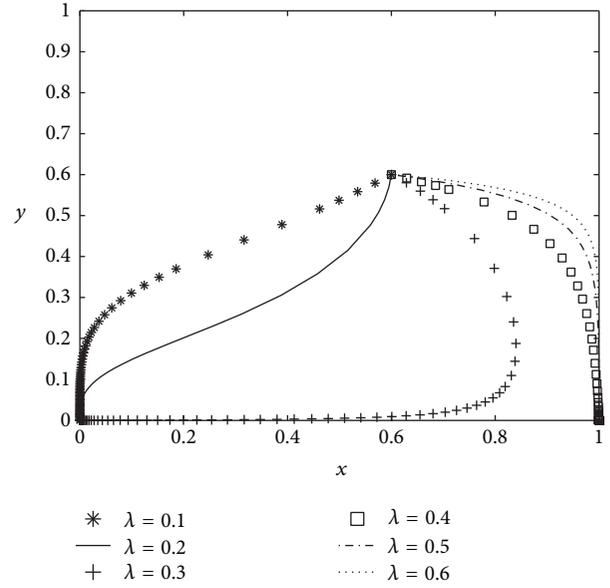


FIGURE 1: When $C_g > R_g$, evolutionary track with the change of λ .

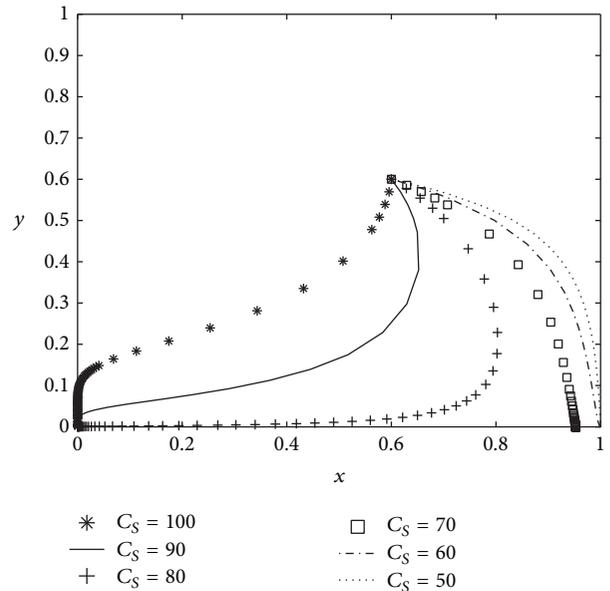


FIGURE 2: When $C_g > R_g$, evolutionary track with the change of C_S .

- (3) Figure 3 shows that as the supervision cost of the government supervision department reduces continually, the system eventually tends to be the stable state of $P_4(1, 1)$. That is, when the supervision cost is greater than the supervision benefit (e.g., $C_g > 15$), the government supervision department will choose nonsupervision strategy, and the private sector will provide low-quality public products/services. Particularly, when $\max((C_g - R_g)/F_g, (C_H + C_S - C_L - F_s)/(R_1 + R_2)) < \lambda < (C_H + C_S - C_L)/(R_1 + R_2 + F_s)$ (e.g., $C_g = 15$), the strategy choice of both parties is uncertain. And when $C_g < R_g$ (e.g., $C_g \leq$

TABLE 5: Local stability analysis of Case 4.

Balance point	$\lambda > \frac{C_H + C_S - C_L}{R_1 + R_2 + F_s}$			$\lambda < \frac{C_H + C_S - C_L}{R_1 + R_2 + F_s}$		
	tr J	det J	Local stability	tr J	det J	Local stability
$P_1(0, 0)$	+	+	Instability point	\pm	-	Saddle point
$P_2(0, 1)$	\pm	-	Saddle point	\pm	-	Saddle point
$P_3(1, 0)$	\pm	-	Saddle point	+	+	Instability point
$P_4(1, 1)$	-	+	ESS	-	+	ESS
$F(x^*, y^*)$	0	\pm	Saddle point	0	\pm	Saddle point

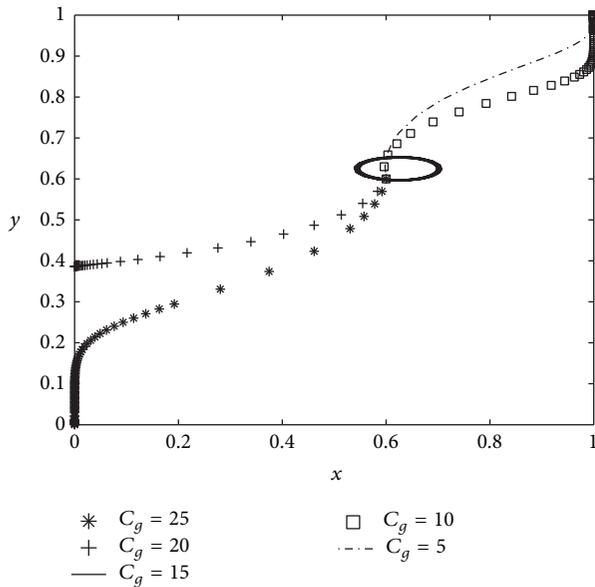


FIGURE 3: Evolutionary track with the change of C_g .

10), the government supervision department will choose supervision strategy, and the private sector will provide high-quality public products/services. Therefore, although the public participation can have constraint on the behavior of private sector to some extent, this is based on the effective supervision of local government. Thus, the supervision enthusiasm should be improved through the continuous reduction of supervision cost.

5. Main Conclusions and Management Insights

5.1. Main Conclusions. This paper builds the evolutionary game model of the private sector and government supervision department with the public participation and analyzes the influence of the public participation level on the PPP projects supervision behavior. The research finds that when the nonsupervision strategy is chosen because the supervision cost of government supervision department is greater than the supervision benefit, it can make private sector consciously provide the high-quality public products/services with the

improvement of public participation level. And, with the reduction of the cost of public participation, the enthusiasm of the private sector choosing to provide high-quality public products/services increases. Meanwhile, with the continuous reduction of supervision cost, the government supervision department will tend to choose supervision strategy.

5.2. Implications for Researchers. This study introduces the supervision problem of PPP projects with the public participation based on evolutionary game, establishes the evolutionary relationship between the government supervision department and private sector, and then explores the effect of the public participation on the result of their decision. The enlightenment for researchers is as follows. Firstly, this paper studies the dynamic game relationship between the government supervision department and private sector based on evolutionary game, which can display the evolutionary trend of their decision in long term. This is different from previous studies. Secondly, the influence of the public participation on the PPP projects supervision behavior is considered. A new perspective on the supervision problem of PPP projects is offered.

5.3. Implications for the Government. Actually, the current operation of the PPP projects focuses on the top-down design method, the public participation level is lower, participation cost is higher [16], and the real demand of the public is not fully reflected. And this is one of the main reasons leading to some projects failure. Therefore, at first, in order to reduce the cost of public participation and improve the level of public participation and then influence the benefit of the private sector and restrain opportunism behavior of the private sector, the government should establish a unified PPP projects management platform through the application of the Internet, big data related technologies, and other advanced technologies. Second, the government supervision department can gather the supervision information at a lower cost through the unified PPP projects management platform and improve the supervision efficiency. Third, the competition mechanism should be introduced so as to provide more choices for the public and improve the level of rights allocation of the public. At this point, the private sector will continuously improve the level of public services to obtain more market share.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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