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Research Article

How to Alleviate Rent-Seeking Behaviour in Performance Appraisal of Government-Paid PPP Projects? Tripartite Evolutionary Game Approach

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Performance appraisal is a key link in the performance payment mechanism of government-paid Public-Private Partnership (PPP) projects. As the performance appraisal of PPP projects is highly professional and complex, it is usually necessary to introduce a third-party performance appraisal institution to evaluate the project outputs of the private investor. However, driven by economic rent, the private investor has the incentive to seek rent from the third party in the performance appraisal process, leading to the low overall performance level of PPP projects and the inability to achieve the PPP performance appraisal goal effectively. To explore how to avoid rent-seeking in performance appraisal and improve the overall performance of government-paid PPP projects, a tripartite evolutionary game model between the behaviour, third party, and the public sector has been constructed. Based on the evolutionary game model, this study analyses the evolutionary stability of each player's strategy, discusses the influence of various factors on the strategy selection of the three-party, and further analyses the stability of the equilibrium point of the three-party game system. The findings reveal that the public sector can slow down the rent-seeking behaviour of the private sector by setting up a reasonable reward and punishment mechanism. The design of a reasonable reward and punishment mechanism must meet the following conditions: (1) the sum of the reward and punishment of all parties is greater than the speculative income; (2) the amount of performance fee withheld for the private investor is greater than the difference between the project operating cost saved and the speculation cost. The research provides technical support for the design of the performance appraisal mechanism of government-paid PPP projects.

1. Introduction

Public-Private Partnership (PPP), compared with the traditional mode, has the advantages of reducing the public sector's financial burden and improving the efficiency of public products and service supply and has been more and more widely used in various countries [1, 2]. Government-paid PPP is an essential part of PPP. In recent years, the London Outer Ring M25 extension project, Sydney Light rail project, and Denver Eagle Light rail project are typical government-paid PPP projects. A scientific and reasonable payment mechanism is one of the keys to implementing government-paid PPP projects successfully. In recent years, the payment mechanism of government-paid PPP has evolved from a usage-based method to a performance-based method [3]. The performance-based payment mechanism focuses more on improving project development and operation efficiency by introducing the private investor's advanced technology, innovation, and management. It can incentivise the private investor to achieve project goals actively; the performance-based payment mechanism can also save costs, transfer risks, and promote innovation in the industry [4, 5].

In practice, the public sector often hires an independent and professional third party performance appraisal institution to evaluate the project outputs of the private investor, and the public sector pays the private investor based on the performance appraisal results [6]. As a third party

organisation, the third party can make up for the shortcomings of the public sector performance supervision and facilitate the supervision of performance appraisal results [7]. However, due to information asymmetry, there are phenomena of rent-seeking in performance appraisal between the private investor and the third party [8, 9]: The profit-seeking nature encourages the private investor not to try his/her best to achieve the performance target but to bribe the third party to obtain more benefits than their actual remuneration. At the same time, driven by interests, the third party may take advantage of its rights to accept bribes. The rent-seeking behaviour between the private and the third party leads to the low overall performance level of PPP projects and the inability to achieve the PPP performance appraisal goal effectively [10]. Therefore, it is necessary to suppress rent-seeking behaviour between the private investor and third party in the performance appraisal to ensure the government-paid PPP projects' overall efficiency.

Although there are many rent-seeking behaviours in PPP performance appraisal [6, 11], the recent studies on PPP project performance management mainly focused on the influencing factors of PPP project performance [12–15], construction and evaluation methods of performance goals, crucial performance indicator systems [16–18], availability payment [19–21], safe payment [22–24], combined payment mechanism [3, 4, 25], and other specific performance payment mechanism designs. Rare attention was paid to the behaviours between the private investor and the third party in performance appraisal, a key part of performance management. For example, Zhang et al. [11] analysed the law of behaviour evolution between the third party and private investor in the performance appraisal of government-paid PPP projects. They revealed the periodic opportunistic behaviour between the private investor and third party. Liang et al. [6] explored the behavioural evolution strategies of the private investor and the third party in PPP project performance appraisal. The findings show that only relying on the third party and the private investor cannot achieve the stable equilibrium state between the strict supervision adopted by the third party and the earnest completion of the performance target strategy adopted by the private sector. By introducing a higher level of supervision and proper intervention to the third party and the private investor, stable equilibrium can be achieved. Then, the public sector-higher level supervision is introduced in this paper to alleviate rent-seeking behaviour in performance appraisal of government-paid PPP projects.

In addition, rent-seeking is essentially opportunistic behaviour, and an incentive mechanism effectively solves opportunistic behaviour. Various incentive mechanisms mainly include reward and punishment mechanisms, government subsidies [26, 27], government support [28], and government guarantees [29]. Therefore, a reward-punishment mechanism is introduced in this paper to suppress the rent-seeking behaviours between the private sector and the third party in the performance appraisal of government-paid PPP projects. This study is different from the above in that, first, the public sector reward and punishment mechanism is introduced to govern rent-seeking behaviour in the performance appraisal of government-paid PPP projects; second, the public sector is introduced into the game, and the influence of the public sector's strategic choice on the strategic choice of the other two parties in the game is explored; third, when certain conditions are met, the private investor and the third party can achieve the expected stable equilibrium in our study.

In summary, this study focuses on the following three aspects for in-depth analysis: (1) Aiming at the rent-seeking behaviour in the PPP project performance appraisal process, this study introduces the public sector reward and punishment mechanism; constructs a tripartite evolutionary game model between the private investor, the third party, and the public sector; and analyses the stability of the strategy of the game parties and the influence of related factors on the strategy. (2) The study uses the Lyapunov indirect method to analyse the stability of the equilibrium points in the tripartite game system and get stable strategy combinations under various conditions. (3) The theoretical results are simulated and analysed using MATLAB R2017b, and countermeasures and suggestions related to the PPP project performance appraisal mechanism are put forward. The remainder of this study is arranged as follows: First, the relevant research on the performance appraisal mechanism of PPP projects is introduced. Second, we construct and analyse a tripartite evolutionary game model and further verify the model through numerical simulation. Finally, we conclude and make relevant suggestions.

2. Literature Review

The recent studies on PPP project performance mainly include the influencing factors of PPP project performance [12–15], construction and evaluation methods of performance goals, key performance indicator systems [16–18], availability payment [19–21], safe payment [22–24], combined payment mechanism [3, 4, 25], and other specific performance payment mechanisms designs. These studies research the performance planning link in the performance management of PPP projects and provide a robust theoretical basis for the subsequent study on the vital link of the PPP project performance payment: performance appraisal. However, none of them involved the research on strategies of participating subjects in the performance appraisal stage.

Existing research on the strategies of participants in PPP projects mainly focuses on the game between the public sector and the private investor. For example, Liu et al. [8] analysed the strategic selection of both the public and the private investor during project operation by evolutionary game theory. Li et al. [9] explored the impact of the level of public participation on the strategy selection of the private investor and government regulators. Gao and Zhao [30] analysed the strategy selection during the game between the government and investors in the new energy power construction PPP project. Rare attention is paid to the impact of rent-seeking behaviour in the performance appraisal of government-paid PPP projects on the overall performance level of PPP projects. McChesney [31] believes that rent-seeking is the act of politicians using their power to help

producers improve their interests and induce producers to pay bribes to obtain the rents they create. Chen et al. [32] believe that rent-seeking behaviour in coal mine safety supervision refers to the behaviour of coal mine safety supervision and other related departments using public power to create rents in order to pursue the economic interests of the department or individual. Liu et al. [33] analysed the rent-seeking behaviour of collusion between firms and government regulators in the coal industry. Cao et al. [34] studied the rent-seeking behaviour of private enterprises bribing government agents in emergency rescue services of government-enterprise cooperation and believed that government regulatory agencies should strengthen the supervision of PPP projects. According to various definitions of rent-seeking, there are also behaviours in which the private investor resorts to bribing the third party to maximise its interests, and the third party uses the public power granted by the public sector to obtain rent in the process of PPP project performance payment. Some scholars have explored rent-seeking behaviour between the private investor and the third party in the performance appraisal process [6, 11]. They show that the private investor and the third party cannot achieve the expected stable equilibrium strategy and that the public sector must intervene appropriately to achieve the expected stable equilibrium strategies. These researches provide a robust theoretical foundation and factual reference for this study. However, rare attention was paid to introducing government reward and punishment mechanisms to govern rent-seeking behaviour in the performance appraisal of government-paid PPP projects.

3. Methodology

3.1. Problem Description. An effective performance appraisal mechanism is critical to the successful operation of government-paid PPP projects. In the process of performance payment for government-paid PPP projects, the public sector commissions third party to conduct a performance appraisal of the private investor's operation of PPP projects and obtains a performance appraisal report; the public sector pays reasonable performance fees to the private investor based on the performance appraisal report; at the same time, the public sector monitors the behaviour of the private investor and the third party. The core of PPP performance appraisal is the following: the third party assesses the performance results of the private investor operation following the performance standards; the private investor provides public infrastructure or services that meet the requirements of the performance standards following the contractual agreement; meanwhile, the public sector supervises the private investor and the third party, which in turn depends on the strategy selections of the third party, the private investor, and the public sector. The three participants in different behaviours will directly affect the final performance appraisal results and the payment amount in the performance appraisal process. The result of performance appraisal is the result of the mutual game of the three participants. In addition, all three participants are finite rational, with the private investor and the third party aiming to maximise their respective interests, and the goal of the public sector is to maximise social benefits. The strategy selection of the three participants evolves gradually over time and stabilises at the optimal strategy. According to related theories and practical issues, the logical relationship between the three participants is shown in Figure 1.

PPP project performance appraisal is a dynamic game process, which can be considered a dynamic equilibrium through the previous analysis. Therefore, this study focuses on rent-seeking behaviour in the performance appraisal process and introduces the performance appraisal mechanism of the public sectors, and a tripartite evolutionary game model between the private investor, the third party, the public sector has been constructed to discuss governance measures for rent-seeking behaviour in the performance appraisal process.

3.2. Basic Assumptions

Assumption 1. Based on the agreed project performance goals, the private investor has two possible strategies: {complete performance goals (CPG), not complete performance goals (NCPG)}; the public sector entrusts the third party to perform performance appraisal on the results of the private investor's operation of PPP project, and the third party has two possible strategies: {reject rent-seeking (RRS), intend rent-seeking (IRS)}; the public sector supervises the private investor and the third party and has two possible strategies: {supervise (S), not supervise (NS)}.

Assumption 2. The performance payment that the private investor can obtain for adopting the CPG strategy is R_{ph}, and the cost paid is W_{ph}; when the private investor adopts the NCPG strategy, and the third party adopts the RRS strategy, the performance payment that the private investor can obtain is R_{pl}, and the cost paid is W_{pl}, where $R_{pl} < R_{ph}$ and $W_{pl} < W_{ph}$. The rent-seeking cost is S when the private investor adopts the NCPG strategy and pays a bribe to the third party who adopts the IRS strategy to obtain total performance payment. The speculative cost of falsifying performance indicator monitoring reports is B_p, where $S + B_p < W_{ph} - W_{pl}$.

Assumption 3. The income obtained by the third party undertaking the performance appraisal business is V. When the third party refuses to rent-seek and the private investor does not complete performance goals, the performance review will not meet the standards; if the third party intends to rent-seek, it will collude with the private investor to help the private investor develop a performance review that meets the standards in order to get paid in full. The speculative cost of the third party's intention to rent-seek is B_s, which mainly includes the cost of falsifying performance appraisal records and issuing false reports.

Assumption 4. When the public sector supervises, if the private investor fails to complete the performance target, it will be fined F_p, and the third party who intends to rent-seek

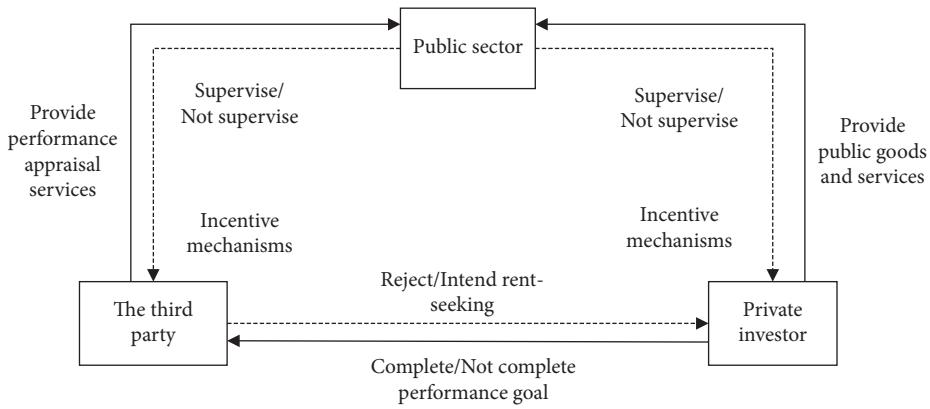

Figure 1: Logical relationship between the three participants.

will be fined F_s. To encourage the private investor to improve project performance, the public sector will reward the private investor for completing performance targets and the third party for refusing to seek rent, and the reward amount is K_p and K_s, respectively. When the public sector does not supervise, it is impossible to obtain information on the behaviour and strategy selection of the private investor and the third party, and the public sector does not make reward and punishment. Let the cost of the public sector supervision be B_g. In addition, the private investor will provide high-quality public products and services when the performance target is completed, and the social benefit is A_g; if the private investor does not complete the performance goal and the public sector does not supervise, this will lead to a lack of supervision and provide the public with poor quality for public products and services, the public sector will be held accountable by higher-level authorities, and the administrative penalty is set to T_g, $T_g > B_g$.

3.3. Payoff Matrix. From the above assumptions, the mixed strategy game matrix between the private investor, the third party, and the public sector is shown in Table 1.

3.4. Model Analysis. Suppose that the private investor adopts the CPG strategy with the probability of x, $x \in [0,1]$; the third party adopts the RRS strategy with the probability of y, $y \in [0,1]$; and the public sector adopts the S strategy with the probability of z, $z \in [0,1]$.

3.4.1. Strategy Stability Analysis of the Private Investor. Suppose that the expected income of the CPG strategy adopted by the private investor is E_{11}, the expected income of the NCPG strategy adopted by the private investor is E_{12}, and the average expected income of the private investor is $\overline{E_1}$; then,

$$\begin{cases} E_{11} = yz\left(R_{ph} - W_{ph} + K_p\right) + y(1-z)\left(R_{ph} - W_{ph}\right) + z(1-y)\left(R_{ph} - W_{ph} + K_p\right) \\ +(1-y)(1-z)\left(R_{ph} - W_{ph}\right), \\ E_{12} = yz\left(R_{pl} - W_{pl} - B_p - F_p\right) + y(1-z) \\ +z(1-y)\left(R_{ph} - W_{pl} - S - B_p - F_p\right) + (1-y)(1-z)\left(R_{ph} - W_{pl} - S - B_p\right), \\ \overline{E_1} = xE_{11} + (1-x)E_{12}. \end{cases} \tag{1}$$

Accordingly, the replicated dynamic equation of the private investor and its first-order derivative and the settings of $G(y)$ can be expressed as follows:

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x\left(E_{11} - \overline{E_1}\right) = x(x-1)\left[W_{ph} - W_{pl} - S - B_p - y\left(R_{ph} - R_{pl} - S\right) - z\left(K_p + F_p\right)\right], \\ F'(x) &= \frac{d(F(x))}{dx} = (2x-1)\left[W_{ph} - W_{pl} - S - B_p - y\left(R_{ph} - R_{pl} - S\right) - z\left(K_p + F_p\right)\right], \\ G(y) &= W_{ph} - W_{pl} - S - B_p - y\left(R_{ph} - R_{pl} - S\right) - z\left(K_p + F_p\right). \end{aligned} \tag{2}$$

Table 1: Evolutionary game matrix between the private investor, third party, and public sector.

Game player		The third party	Public sector	
			Supervise	Not supervise
Private investor	Complete performance goals	Reject rent-seeking	$R_{ph} - W_{ph} + K_p$, $V + K_s$, $A_g - B_g - K_p - K_s$	$R_{ph} - W_{ph}$, V, A_g
		Intend rent-seeking	$R_{ph} - W_{ph} + K_p$, $V - B_s - F_s$, $A_g - B_g - K_p + F_s$	$R_{ph} - W_{ph}$, $V - B_s$, A_g
	Not complete performance goals	Reject rent-seeking	$R_{pl} - W_{pl} - B_p - F_p$, $V + K_s$, $-B_g - K_s + F_p$	$R_{pl} - W_{pl} - B_p$, V, $-T_g$
		Intend rent-seeking	$R_{ph} - W_{pl} - S - B_p - F_p$, $V + S - B_s - F_s$, $-B_g + F_p + F_s$	$R_{ph} - W_{pl} - S - B_p$, $V + S - B_s$, $-T_g$

From the stability theorem of the differential equation, the probability of the CPG strategy adopted by the private investor in a stable state must satisfy $F(x) = 0$ and $F'(x) < 0$; then,

(1) When $y = y^* = [W_{ph} - W_{pl} - S - B_p - z(K_p + F_p)]/(R_{ph} - R_{pl} - S)$, then $F(x) \equiv 0$, and all x are in a stable state.

(2) When $y \neq y^*$, we can get two equilibrium points: $x = 0$, $x = 1$. Because of $\partial G(y)/\partial y < 0$, $G(y)$ is a decreasing function with respect to y. There are two situations for discussion as follows:

① When $y < y^*$, $G(y) > 0$, then $F'(x)|_{x=0} < 0$ and $x = 0$ is the stable strategy of the private investor

② When $y > y^*$, $G(y) < 0$, then $F'(x)|_{x=0} < 0$ and $x = 1$ is the stable strategy of the private investor

The strategy evolution phase diagram of the private investor is shown in Figure 2.

The probability of the NCPG strategy adopted by the private investor stably is the volume of A_1: V_{A_1}, and the probability of the CPG strategy adopted by the private investor stably is the volume of A_2: V_{A_2}, calculated by

$$V_{A_1} = \int_0^1 \int_0^1 \frac{\left[W_{ph} - W_{pl} - S - B_p - z\left(K_p + F_p\right)\right]}{\left(R_{ph} - R_{pl} - S\right)} \mathrm{d}z\mathrm{d}x,$$

$$= \frac{\left[2\left(W_{ph} - W_{pl} - S - B_p\right) - \left(K_p + F_p\right)\right]}{2\left(R_{ph} - R_{pl} - S\right)},$$

$$V_{A_2} = 1 - V_{A_1} = 1 - \frac{\left[2\left(W_{ph} - W_{pl} - S - B_p\right) - \left(K_p + F_p\right)\right]}{2\left(R_{ph} - R_{pl} - S\right)}. \tag{3}$$

Corollary 1. *The probability of the CPG strategy adopted by the private investor is positively related to the private investor rent-seeking costs, speculative costs, performance fees withholding amount, and public sector rewards and punishments and negatively related to the cost savings of the NCPG strategy adopted by the private investor.*

Proof 1. Find the first-order partial derivative of each element in expression V_{A_1}: $\partial V_{A_2}/\partial S > 0$, $\partial V_{A_2}/\partial B_p > 0$, $\partial V_{A_2}/\partial(R_{ph} - R_{pl}) > 0$, $\partial V_{A_2}/\partial(K_p + F_p) > 0$, $\partial V_{A_2}/\partial(W_{ph} - W_{pl}) < 0$. Therefore, an increase in S, B_p, $(R_{ph} - R_{pl})$, and $(K_p + F_p)$ or a decrease in $(W_{ph} - W_{pl})$ will increase the probability of the CPG strategy adopted by the private investor.

Corollary 1 shows that the public sector can increase performance fees withheld for the private investor and increase the rewards and penalties to prevent the private investor from not completing the performance goal. Furthermore, the public sector can increase the speculation cost of the private investor by enhancing public participation and media supervision to encourage the private investor to complete the performance goal. □

Corollary 2. *In the evolutionary game process, the probability of the CPG strategy adopted by the private investor increases with the increase in the probability of the RRS strategy adopted by the third party and the increase in the probability of the S strategy adopted by the public sector.*

Proof 2. It can be seen from the analysis of the stability of the private investor strategy that when $y < y^*$, $z < [W_{ph} - W_{pl} - S - B_p - y(R_{ph} - R_{pl} - S)]/(K_p + F_p)$, then $x = 0$ is an evolutionary equilibrium strategy; on the contrary, $x = 1$ is an evolutionary equilibrium strategy. Therefore, with the gradual increase of y and z, the stabilisation strategy of the private investor has evolved from $x = 0$ (NCPG) to $x = 1$ (CPG).

Corollary 2 shows that increasing the probability of the RRS strategy adopted by the third party can increase the probability of the CPG strategy adopted by the private investor. Therefore, the public sector can not only prompt the private investor to complete performance goal by increasing the probability of its supervision, but also develop the impartiality of the third party, such as improving the third party's sense of social responsibility and credibility, and give full play to social forces, such as the public and the media encouraging the private investor to complete performance goal. □

3.4.2. Strategy Stability Analysis of the Third Party. The expected income of the RRS strategy adopted by the third party is E_{21}, the expected income of the IRS strategy adopted by the third party is E_{22}, and the average expected income of the third party is $\overline{E_2}$; then,

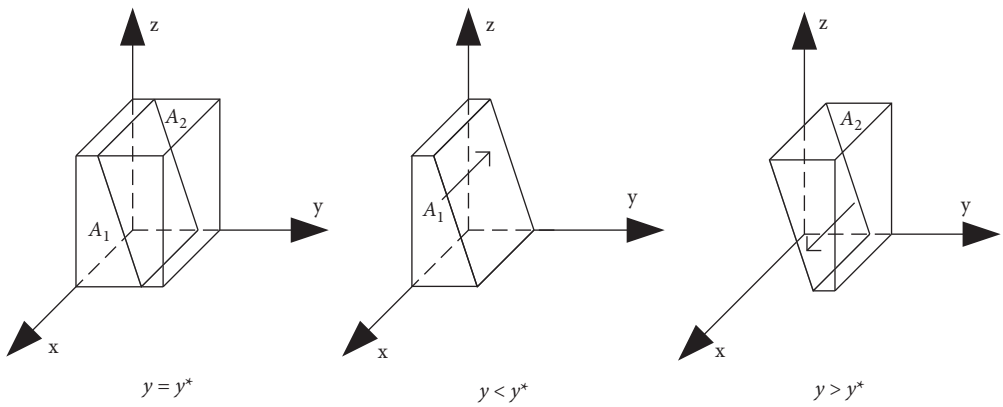

Figure 2: Strategy evolution phase diagram of the private investor.

$$\begin{cases} E_{21} = xz(V + K_s) + x(1-z)V + (1-x)z(V + K_s) + (1-x)(1-z)V, \\ E_{22} = xz(V - B_s - F_s) + x(1-z)(V - B_s) + (1-x)z(V + S - B_s - F_s) \\ + (1-x)(1-z)(V + S - B_s), \\ \overline{E_2} = yE_{21} + (1-y)E_{22}. \end{cases} \tag{4}$$

The replicated dynamic equation of the third party and its first-order derivative can be expressed as follows:

$$F(y) = \frac{dy}{dt} = y(E_{21} - \overline{E_2}) = y(y-1) \cdot [(1-x)S - z(K_s + F_s) - B_s],$$

$$F'(y) = \frac{d(F(y))}{dy} = (2y-1)[(1-x)S - z(K_s + F_s) - B_s]. \tag{5}$$

Similarly, the strategy evolution phase diagram of the third party is shown in Figure 3.

$$z = z^* \; z < z^* \; z > z^*. \tag{6}$$

The probability of the IRS strategy adopted by the third party stably is the volume of B_1: V_{B_1}, and the probability of the RRS strategy adopted by the third party stably is the volume of B_2: V_{B_2}, where the tangent plane passes through the point $((S - B_s)/S, 0, 0)$, calculated by

$$V_{B_1} = \int_0^1 \int_0^{(S-B_s)/S} \frac{[(1-x)S - B_s]}{(K_s + F_s)} dx dy = \frac{(S - B_s)^2}{2(K_s + F_s)S},$$

$$V_{B_2} = 1 - V_{B_1} = 1 - \frac{(S - B_s)^2}{2(K_s + F_s)S}. \tag{7}$$

Corollary 3. *The probability of the RRS strategy adopted by the third party is positively related to its speculative cost and public sector rewards and penalties and negatively related to rent-seeking revenue. The proof is similar to proof 1 and is omitted here.*

Corollary 3 shows that the public sector can curb rent-seeking behaviour by increasing the third party's rewards and penalties, and the public sector can also increase the speculative cost of the third party by enhancing public participation and media supervision to prompt the third party to conduct performance appraisals profoundly and fairly. Furthermore, when the rent-seeking income of the third party is high, it will cause rent-seeking behaviour; the public sector should strengthen the supervision of the third party to avoid rent-seeking behaviour.

Corollary 4. *In the evolutionary game process, the probability of the RRS strategy adopted by the third party increases with the increase in the probability of the CPG strategy adopted by the private investor and the S strategy adopted by the public sector. The proof is similar to proof 2, so it is omitted here.*

Corollary 4 shows that the third party's stabilisation strategy selection is affected by the strategy selections of the private investor and the public sector. For example, the behaviour of the public sector adopting the S strategy and the private investor adopting the CPG strategy can encourage the third party to adopt the RRS strategy as a stabilisation strategy. Therefore, the public sector must take strict supervision measures, encourage the private investor to operate projects following performance standards, cultivate the private investor's sense of social responsibility and contract spirit, and adopt other measures to ensure the fairness of the third party assessments and improve the overall performance level of PPP projects.

(1) The probability of the CPG strategy adopted by the private investor is positively related to the cost of rent-seeking in the private investor, speculative costs, fees withheld for not completing performance goals, and public sector rewards and penalties and negatively related to the

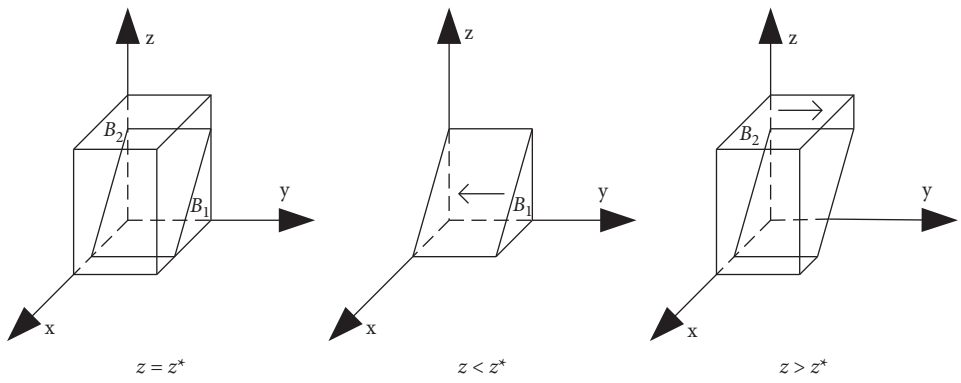

Figure 3: Strategy evolution phase diagram of the third party.

cost savings for the private investor adopting the NCPG strategy; the probability of the RRS strategy adopted by the third party is positively related to the cost of speculation and the amount of rewards and penalties from the public sector and negatively related to the benefits of rent-seeking; the probability of the S strategy adopted by the public sector is positively related to the fines imposed on the private investor and the administrative penalties imposed by the higher authority and negatively related to the rewards to the private investor and the third party and the cost of the public sector supervision, and the relationship with the amount of penalties imposed by the public sector on the third party intending rent-seeking is influenced by multiple factors.

3.4.3. Strategy Stability Analysis of the Public Sector. Suppose that the expected income of the S strategy adopted by the public sector is E_{31}, the expected income of the NS strategy adopted by the public sector is E_{32}, and the average expected income of the public sector is $\overline{E_3}$; then,

$$\begin{cases} E_{31} = xy\left(A_g - B_g - K_p - K_s\right) + x(1-y)\left(A_g - B_g - K_p + F_s\right) \\ + (1-x)y\left(-B_g - K_s + F_p\right) + (1-x)(1-y)\left(-B_g + F_p + F_s - D_g\right), \\ E_{32} = xyA_g + x(1-y)A_g + (1-x)y\left(-T_g\right) + (1-x)(1-y)\left(-T_g - D_g\right), \\ \overline{E_3} = zE_{31} + (1-z)E_{32}. \end{cases} \tag{8}$$

The replicated dynamic equation of the public sector and its first-order derivative is

$$\begin{aligned} F(z) &= \frac{dz}{dt} = z\left(E_{31} - \overline{E_3}\right) = z(z-1)\left[x\left(F_p + K_p + T_g\right) + y\left(K_s + F_s\right) + B_g - F_p - F_s - T_g\right], \\ F'(z) &= \frac{d(F(z))}{dz} = (2z-1)\left[x\left(F_p + K_p + T_g\right) + y\left(K_s + F_s\right) + B_g - F_p - F_s - T_g\right]. \end{aligned} \tag{9}$$

Similarly, the strategy evolution phase diagram of the public sector is shown in Figure 4.

The probability of the S strategy adopted by the public sector stably is the volume of C_1: V_{C_1}, and the probability of

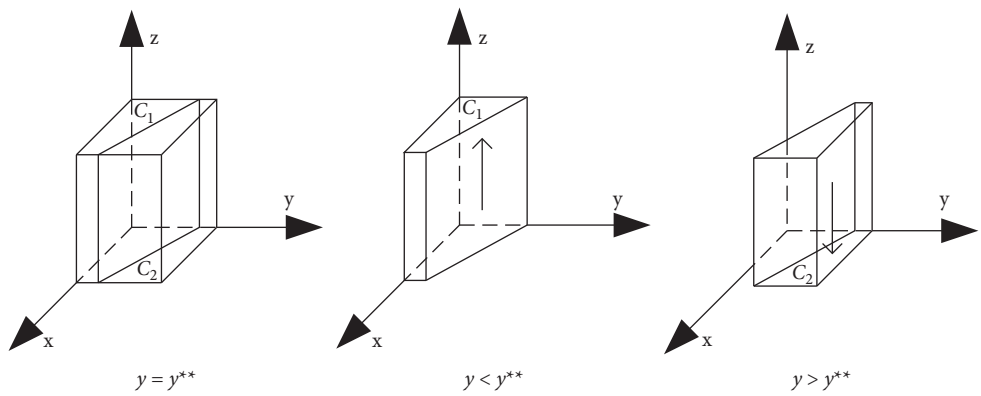

Figure 4: Strategy evolution phase diagram of the public sector.

the NS strategy adopted by the public sector stably is the volume of C_2: V_{C_2}, calculated by

$$V_{C_1} = \int_0^1 \int_0^1 \frac{\left[F_p + F_s + T_g - B_g - x\left(F_p + K_p + T_g\right)\right]}{\left(K_s + F_s\right)} \mathrm{d}x\mathrm{d}z$$

$$= \frac{\left[F_p + T_g - K_p + 2\left(F - B_g\right)\right]}{2\left(K_s + F_s\right)},$$

$$V_{C_2} = 1 - V_{C_1} = 1 - \frac{\left[F_p + T_g - K_p + 2\left(F - B_g\right)\right]}{2\left(K_s + F_s\right)}. \tag{10}$$

Corollary 5. . *The probability of the S strategy adopted by the public sector is positively related to public sector penalties on the private investor and administrative penalties for inadequate public sector supervision and negatively related to the public sector rewards given to other parties and the cost of public sector supervision, and the relationship with the number of public sector penalties for intentional rent-seeking by third parties is influenced by multiple factors. The proof is similar to proof 1 and is omitted here.*

Corollary 5 shows that the higher the number of penalties set by the public sector is, the more it can promote public sector supervision. The higher the number of rewards set, the lower the public sector supervision rate, the heavier the administrative penalties imposed on the public sector by the higher authorities, and the more the public sector supervision. On the other hand, reducing supervision costs can also further promote the public sector supervision.

Corollary 6. *In the evolutionary game process, the probability that the public sector adopts the S strategy decreases with the increase in the probability that the private investor adopts the CPG strategy and the probability of the RRS strategy adopted by the third party. The proof is similar to proof 2, so it is omitted here.*

Corollary 6 shows that the probability of the S strategy adopted by the public sector is closely related to the probability of the CPG strategy adopted by the private investor and the probability of the RRS strategy adopted by the third party. Therefore, when the private investor adopts the CPG strategy with a high probability, or the third party adopts the RRS strategy with a high probability, the public sector will reduce its supervision, leading to the lack of supervision by the public sector.

3.4.4. ESS Analysis of the Equilibrium Point of the Tripartite Evolutionary Game System. Eight equilibrium points can be obtained through equation system $F(x) = 0$, $F(y) = 0$, $F(z) = 0$: $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(0,1,1)$, $E_8(1,1,1)$.

The Jacobian matrix of the three-party evolutionary game system is

$$J=\begin{bmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{bmatrix}=\begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial x} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix},$$

$$\begin{bmatrix} (2x-1)\begin{bmatrix} W_{ph}-W_{pl111}-S-B_p \\ -y\left(R_{ph}-R_{pl}-S\right)-z\left(K_p+F_p\right) \end{bmatrix} & x(x-1)\left(S-R_{ph}+R_{pl}\right) & x(x-1)-\left(K_p-F_p\right) \\ y(y-1)(-S) & (2y-1)[(1-x)S-z\left(K_s+F_s\right)-B_s] & y(y-1)\left(-K_s-F_s\right) \\ z(z-1)\left(K_p+F_p+T_g\right) & z(z-1)\left(K_s+F_s\right) & (2z-1)\begin{bmatrix} x\left(K_p+F_p+T_g\right)+y\left(K_s+F_s\right) \\ +B_g-F_p-F_s-T_g \end{bmatrix} \end{bmatrix}. \tag{11}$$

The Lyapunov indirect method is used [35] to analyse the stability of the equilibrium point. The stability analysis of each equilibrium point is shown in Table 2.

① $W_{pl}-W_{ph}+S+B_p+K_p+F_P<0$, $B_s-S+K_s+F_s<0$

② $W_{ph}-W_{pl}-B_p-R_{ph}+R_{pl}<0$

③ $W_{pl}-W_{ph}+B_p+R_{ph}-R_{pl}+K_p+F_P<0$, $S-B_s-K_s-F_s<0$, $K_s+B_g-F_p-T_g<0$

Corollary 7. *When* $K_p+F_P<W_{ph}-W_{pl}-B_p-S$, $K_s+F_s<S-B_s$, *and* $W_{ph}-W_{pl}-B_p<R_{ph}-R_{pl}$, *the replicated dynamic system has two stable points:* $E_4(0,0,1)$ *and* $E_5(1,1,0)$.

Proof. According to Table 2, conditions ① and ② are met, so the equilibrium points $E_4(0,0,1)$ and $E_5(1,1,0)$ are the asymptotic stability points of the system. Condition ③ is not satisfied, so the equilibrium point $E_7(0,1,1)$ is an unstable point.

Corollary 7 shows that when the private investor's rewards and penalties are small, performance fee withheld is large, and the third party's rewards and penalties are small, or the rent-seeking income of the private investor and the third party is significant, but the private investor's speculative income is lower than performance fee withheld, the evolution of the strategy portfolio is stable at two stable points: (NCPG, IRS, S) and (CPG, RRS, NS). At this time, public sector supervision is ineffective. It cannot restrict the behaviour of the private investor and the third party, which leads to the low overall performance of PPP projects and a decline in social benefits. To restrain the evolution of the strategy portfolio from being stable at point (NCPG, IRS, S), the public sectors must set sufficiently large rewards or penalties to function as a reward and punishment mechanism. □

Corollary 8. *When* $R_{ph}-R_{pl}+K_p+F_P<W_{ph}-W_{pl}-B_p$, $S-B_s<K_s+F_s$, *and* $K_s+B_g<F_p+T_g$, *the system has a stable point* $E_7(0,1,1)$. *The proof process is similar to that of Corollary 7, so it is omitted here.*

Corollary 8 shows that when the rewards, penalties, and performance fee withheld for the private investor are low, the reward and punishment for third parties are relatively large, and the administrative penalties imposed on the public sector by the superior authorities are relatively high, or private investor speculation gains and third party speculation gains are relatively small, and the public sector's supervision costs are low, the tripartite behaviour strategy evolves stably to the strategic combination (NCPG, RRS, S). At this time, although rent-seeking behaviour will not occur, the public sector's supervision is still ineffective. Due to the significant speculative returns of the private investor or improper rewards and punishment mechanism set by the public sector, the private investor will eventually adopt the NCPG strategy. Therefore, the public sector should set up an effective reward and punishment mechanism for the private investor and third parties while reducing its supervision costs as much as possible to avoid the emergence of a stable strategy portfolio (NCPG, RRS, S).

Corollary 9. *When* $K_p+F_P>W_{ph}-W_{pl}-S-B_p>0$, $K_s+F_s>S-B_s>0$, *and* $R_{ph}-R_{pl}>W_{ph}-W_{pl}-B_p$, *the system has a stable point* $E_5(1,1,0)$. *The proof process is similar to that of Corollary 7, so it is omitted here.*

Corollary 9 shows that when the sum of the reward and punishment of all parties is greater than the speculative

Table 2: Stability analysis of the system equilibrium point.

Equilibrium point	Jacobian matrix eigenvalues $\lambda_1\ \lambda_2, \lambda_3$	Real part symbol	Stability conclusion	Condition
$E_1(0,0,0)$	$W_{pl}-W_{ph}+S+B_p,\ B_s-S,\ F_p+F_s+T_g-B_g$	$(-,-,+)$	Unstable point	\
$E_2(1,0,0)$	$W_{ph}-W_{pl}-S-B_p,\ B_s,\ F_s-K_p-B_g$	$(+,+,\times)$	Unstable point	\
$E_3(0,1,0)$	$W_{pl}-W_{ph}+B_p+R_{ph}-R_{pl},\ S-B_s,\ F_p+T_g-K_s-B_g$	$(\times,+,\times)$	Unstable point	\
$E_4(0,0,1)$	$W_{pl}-W_{ph}+S+B_p+K_p+F_p,\ B_s-S+K_s+F_s,\ B_g-F_p-F_s-T_g$	$(-,-,-)$	*ESS*	①
$E_5(1,1,0)$	$W_{ph}-W_{pl}-B_p-R_{ph}+R_{pl},\ -B_s,\ -K_p-K_s-B_g$	$(-,-,-)$	*ESS*	②
$E_6(1,0,1)$	$W_{ph}-W_{pl}-S-B_p-K_p-F_P,\ K_s+F_s+B_s,\ K_p+B_g-F_s$	$(\times,+,\times)$	Unstable point	\
$E_7(0,1,1)$	$W_{pl}-W_{ph}+B_p+R_{ph}-R_{pl}+K_p+F_P,\ S-B_s-K_s-F_s,\ K_s+B_g-F_p-T_g$	$(-,-,-)$	*ESS*	③
$E_8(1,1,1)$	$W_{ph}-W_{pl}-B_p-R_{ph}+R_{pl}-K_p-F_P,\ -B_s-K_s-F_s,\ K_p+K_s+B_q$	$(\times,-,+)$	Unstable point	\

Note. × means the symbol is uncertain. If the condition corresponding to the equilibrium point is not satisfied, the equilibrium point is unstable or meaningless.

income, and the amount of performance fee withheld for private investor is greater than the difference between the project operating cost and the speculation cost saved, the tripartite behaviour strategy evolves and stabilises at strategy combination (CPG, RRS, NS). In addition, changes in the number of administrative penalties imposed on the public sector by the superior authority will not affect this evolutionary stability result. Therefore, the public sector should set a reasonable reward and punishment mechanism for the private investor and third parties to avoid system evolution stabilising at a strategic combination (NCPG, IRS, S). This shows that a reasonable reward and punishment mechanism set by the public sector can effectively avoid rent-seeking behaviour between the private investor and the third party and encourage both parties to complete their respective tasks reasonably and equitably to maximise social benefits.

4. Simulation Analysis

To further verify the validity of the model and evolutionary stability analysis in this study, this study takes actual projects in China as an example to discuss the stability of the equilibrium solution of the three-party game system of the third party, the private investor, and the public sector under different conditions.

4.1. Case Background. Project A is a municipal road in a city in China. The project includes municipal roads, pipe networks, greening, and other supporting projects. The total length is 69.33 km, and the total investment is 556.2 million USD, of which construction and installation costs are 386.25 million USD, and demolition and other costs are 169.95 million USD. The project return mechanism is the government payment method. During the operation period of the project, the government takes all direct payment responsibilities. The government's annual direct payment to private investor includes the average annual construction cost, annual operation cost, and reasonable profit. Because it is hard to obtain the actual data, this study makes three reasonable hypotheses for the following parameters according to the actual situation. Array 1 ($K_p = 10$, $F_p = 20$, $W_{ph} - W_{pl} = 80$, $B_p = 10$, $S = 30$, $K_s = 5$, $F_s = 10$, $B_s = 5$, $R_{ph} - R_{pl} = 100$) satisfies the conditions of Corollary 7. Array 2 ($R_{ph} - R_{pl} = 70, K_p = 10, F_p = 20\ W_{ph} - W_{pl} = 120$, $B_p = 10$, $S = 20$, $B_s = 20$, $K_s = 10$, $F_s = 20$, $B_g = 10$, $T_g = 20$) satisfies the conditions of Corollary 8. Array 3 ($K_p = 20$, $F_p = 40$, $W_{ph} - W_{pl} = 60$ $B_p = 10$, $S = 20$ $K_s = 15$, $F_s = 30$, $B_s = 5$, $R_{ph} - R_{pl} = 100$) satisfies the conditions of Corollary 9.

4.2. Model Application. Substituting the data in array 1 into the Jacobian matrix shows that the eigenvalue $W_{pl} - W_{ph} + S + B_p + K_p + F_P = -10 < 0$, $B_s - S + K_s + F_s = -10 < 0$, $B_g - F_p - F_s - T_g = -40 < 0$ corresponding to the equilibrium point $E_4(0,0,1)$ satisfies the stability condition; the eigenvalue $W_{ph} - W_{pl} - B_p - R_{ph} + R_{pl} = -30 < 0$, $-B_s = -5 < 0$, $-K_p - K_s - B_g = -25 < 0$ corresponding to the equilibrium point $E_5(1,1,0)$ satisfies the stability condition; and the remaining equilibrium points do not satisfy the stability condition, so only $E_4(0,0,1)$ and $E_5(1,1,0)$ are the asymptotically stable points of the system, and Corollary 7 holds.

Substituting the data in array 2 into the Jacobian matrix shows that the eigenvalue $W_{pl} - W_{ph} + B_p + R_{ph} - R_{pl} + K_p + F_P = -10 < 0$, $S - B_s - K_s - F_s = -20 < 0$, $K_s + B_g - F_p - T_g = -20 < 0$ corresponding to the equilibrium point $E_7(0,1,1)$ satisfies the stability condition. The other equilibrium points do not satisfy the stability condition, so only $E_7(0,1,1)$ is the system's asymptotically stable point, and Corollary 8 holds.

Similarly, substituting the data in array 3 into the Jacobi matrix shows that the equilibrium point $E_5(1,1,0)$ corresponds to an eigenvalue $W_{ph} - W_{pl} - B_p - R_{ph} + R_{pl} = -50 < 0$, $-B_s = -5 < 0$, $-K_p - K_s - B_g = -45 < 0$, satisfying the stability condition, and the rest of the equilibrium points do not satisfy the stability condition, so only $E_5(1,1,0)$ is the asymptotically stable point of the system, and Corollary 9 holds.

4.3. Numerical Simulation. To verify Corollaries 7–9, according to the assumptions of Project A, arrays 1–3 meet the conditions in Corollaries 7–9 and are evolved from

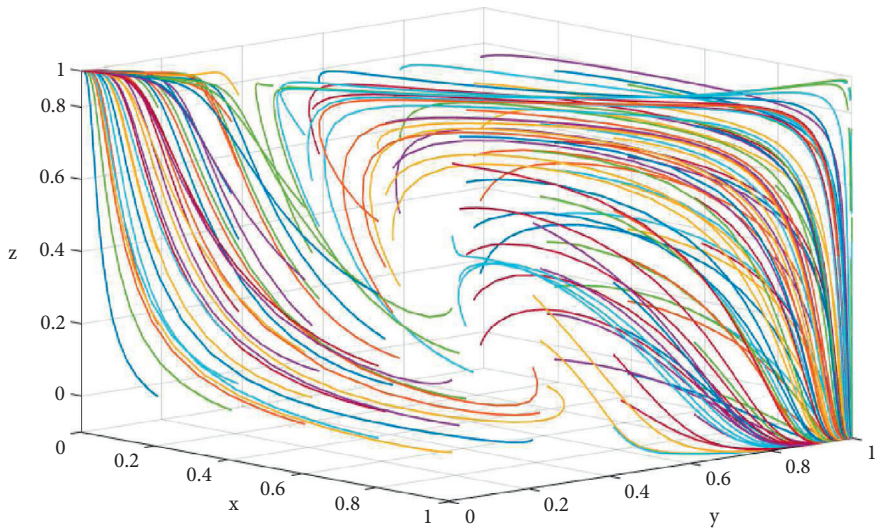

Figure 5: The simulation results of array 1.

different initial strategies combinations over time. The results are as follows:

(1) Array 1 ($K_p = 10$, $F_p = 20$, $W_{ph} - W_{pl} = 80$, $B_p = 10$, $S = 30$, $K_s = 5$, $F_s = 10$, $B_s = 5$, $R_{ph} - R_{pl} = 100$) satisfies the conditions in Corollary 7. The simulation results are shown in Figure 5, and Corollary 7 is verified at this time.

When the system meets Corollary 7, the simulation results clearly show that there are two stable points in the system, namely, the private investor, the third party, and the public sector's strategic combination (NCPG, IRS, S) and (CPG, RRS, NS), a combination of two stable evolutionary strategies.

(2) Array 2 ($R_{ph} - R_{pl} = 70$, $K_p = 10$, $F_p = 20$, $W_{ph} - W_{pl} = 120$, $B_p = 10$, $S = 20$, $B_s = 20$, $K_s = 10$, $F_s = 20$, $B_g = 10$, $T_g = 20$) satisfies the conditions of Corollary 8. It can be seen from Figure 6 that Corollary 8 is verified.

When the system satisfies Corollary 8, the simulation results show that there is a stable point $E_7(0, 1, 1)$, that is, the three-party strategy combination of the game subject (NCPG, RRS, S).

(3) Array 3 ($K_p = 20$, $F_p = 40$, $W_{ph} - W_{pl} = 60$, $B_p = 10$, $S = 20$, $K_s = 15$, $F_s = 30$, $B_s = 5$, $R_{ph} - R_{pl} = 100$) satisfies the conditions of Corollary 9. It can be seen from Figure 7 that Corollary 9 is verified.

When the system satisfies Corollary 9, the simulation results show that there is only one stable point, $E_5(1, 1, 0)$; that is, the strategic combination of three parties in the game is stable (CPG, RRS, NS).

It can be seen from Figures 5–7 that the simulation results of arrays 1–3 are consistent with the conclusions of Corollaries 7–9, respectively, verifying the model and stability analysis results of this article. Therefore, to avoid the mixed strategy in Corollary 7 and the ineffective public sector supervision in Corollary 8, the public sectors should set up reasonable reward and punishment mechanism for the private investor and third parties; for example, the sum of reward and punishment for the private investor and third parties should be higher than the income obtained through rent-seeking, thereby improving the overall performance of the PPP project and maximising social benefits. The simulation results are consistent and valid with the conclusions of the stability analysis of the game system, indicating that the analysed conclusions have practical guidance for the performance regulation of PPP projects.

5. Discussion

In order to alleviate the rent-seeking behaviour in the performance appraisal process of government-paid PPP projects, this paper constructs a tripartite evolutionary game model to analyse the strategy selection of the three parties and the stability of the game system under different circumstances. Consequently, several findings and suggestions are put forward.

First, different from existing researches on PPP project performance payment, this study notes the phenomena of rent-seeking in performance appraisal between the private investor and the third party and introduces the performance appraisal mechanism of the public sector to study how to suppress such rent-seeking behaviour to improve the overall performance level of PPP projects by introducing the performance appraisal mechanism of the public sector to provide a theoretical basis for improving the PPP performance appraisal mechanism.

Then, by analysing the stability of the three parties' strategies, it is found that the strategy selections of the three parties of the game are interactive. Increasing the probability of the RRS strategy adopted by the third party can increase the probability of the CPG strategy adopted by the private investor; the public sector supervision and the private investor completion of performance goals can both prompt the third party to adopt the RRS strategy as a stable strategy; when the probability of the CPG strategy adopted by the private investor

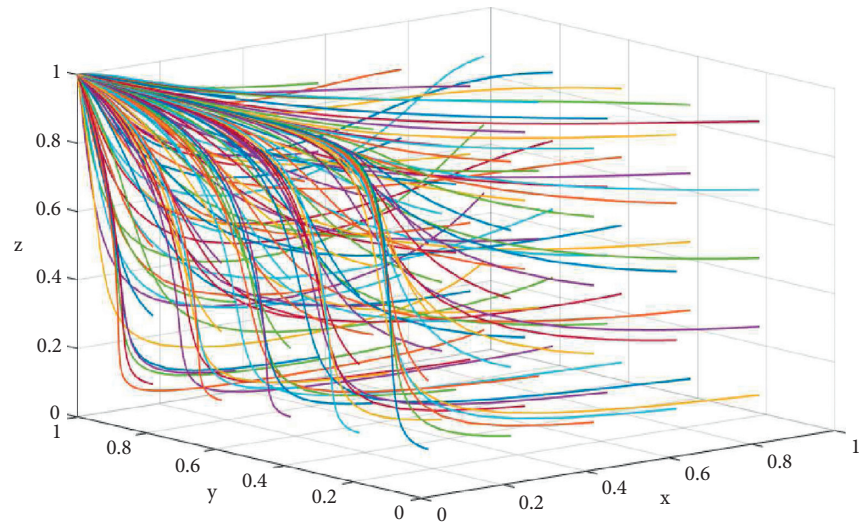

Figure 6: The simulation results of array 2.

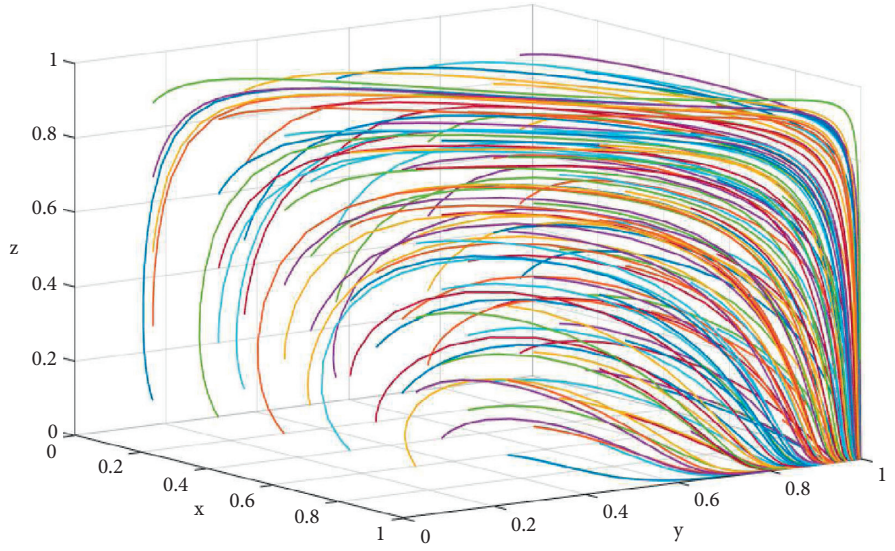

Figure 7: The simulation results of array 3.

and the RRS strategy adopted by the third party is greater, the public sector will reduce the probability of its supervision, leading to the lack of supervision by the public sectors. In addition, through the analysis of the stability of the equilibrium point in the game system, it is found that the evolutionary game system includes three gradual stability points: (NCPG, IRS, S), (CPG, RRS, NS), and (NCPG, RRS, S), and this study verifies the conclusions through case simulation.

Finally, relevant suggestions are put forward based on the conclusions. In the PPP performance appraisal process, we suggest the following: (1) The strategy selections of the three parties of the game are interactive. The public sector can promote the third party to adopt the RRS strategy and encourage the private investor to adopt the CPG strategy by enhancing the public sector supervision, developing the impartiality of the third party, and cultivating social responsibility and contract spirit of the private investor. (2) The public sector can also restrain rent-seeking behaviours between the private investor and the third party by increasing public participation and media supervision, which encourages the private investor to complete performance goals and the third party to refuse to rent-seek. (3) To avoid the ineffective public sector supervision as shown in Corollaries 7 and 8, the public sector should set up a reasonable reward and punishment mechanism, and the design of this mechanism must meet the following conditions: first, the sum of the reward and punishment of all parties is greater than the speculative income; second, the amount of performance fee withheld for private investor is greater than the difference between the project operating cost saved and the speculation cost.

6. Conclusions, Contribution, and Limitations

6.1. Conclusions. This study introduces the government reward and punishment mechanism to govern the rent-seeking behaviour between the private investor and the third party in the performance appraisal process of PPP projects and draws the following conclusions:

(1) The probability of the CPG strategy adopted by the private investor is positively related to the cost of rent-seeking in the private investor, speculative costs, fees withheld for not completing performance goals, and public sector rewards and penalties and negatively related to the cost savings for the private investor adopting the NCPG strategy; the probability of the RRS strategy adopted by the third party is positively related to the cost of speculation and the amount of rewards and penalties from the public sector and negatively related to the benefits of rent-seeking; the probability of the S strategy adopted by the public sector is positively related to the fines imposed on the private investor and the administrative penalties imposed by the higher authority and negatively related to the rewards to the private investor and the third party and the cost of the public sector supervision, and the relationship with the amount of penalties imposed by the public sector on the third party intending rent-seeking is influenced by multiple factors.

(2) The strategy selections of the three parties of the game are interactive. Increasing the probability of the RRS strategy adopted by the third party can increase the probability of the CPG strategy adopted by the private investor; the public sector supervision and the private investor completion of performance goals can both prompt the third party to adopt the RRS as a stable strategy; when the probability of the CPG strategy adopted by the private investor or the probability of the RRS strategy adopted by the third party is greater, the public sector will reduce the probability of its supervision, which will lead to the phenomenon of lack of supervision by the public sector.

(3) The public sector should set a reasonable reward and punishment mechanism in line with the conditions that the sum of the reward and punishment of each party is more significant than its speculative income, the amount of performance fee withheld for the private investor is greater than the difference between its savings in project operating costs and speculative costs, to make sure that the game converges to the expected stable equilibrium state: the private investor completion of performance goal and the third party refusal of rent-seeking.

(4) Increasing the number of rewards will lead to the lack of supervision by the public sector, which is not conducive to the public sector's performance of its supervision responsibilities. However, the accountability of the higher authority to the public sector's dereliction of duty is of great significance to improving the overall performance of the PPP project.

6.2. Theoretical Contribution. The contribution of this study to the theoretical knowledge system of PPP is mainly reflected in the following points: First, it has improved the performance appraisal mechanism of government-paid PPP projects, and the introduction of the government's reward and punishment mechanism can effectively avoid the behaviour of private investor seeking rent from the third party. Second, it has provided technical support for the design of the government's reward and punishment mechanism and put forward the conditions that must be met for a reasonable government reward and punishment mechanism design. Third, it has improved the theory of performance management of government-paid PPP projects. Performance appraisal is a key link of the performance payment of government-paid PPP projects. Through the governance of third party rent-seeking behaviours from the private sector in the PPP performance appraisal process, the project's overall performance can be improved, and technical support for the sustainable development of PPP projects can be provided.

6.3. Limitations. There is no doubt that this study has some limitations. First, due to the complexity, this study does not analyse the stability of the mixed strategy in the game system. Future work can analyse the stability of the mixed strategy more comprehensively. Second, the public is the ultimate beneficiary of PPP infrastructure and services and can give feedback on the relevant performance of PPP projects directly, and public media has specific dissemination and supervision capabilities. This study has not considered the influence of the public and public media. Future research can introduce the supervision of the public and public media to explore how to effectively play the role of supervision of the public and the media, better curb rent-seeking behaviours between the private investor and third parties, and improve the overall performance of PPP projects. In addition, it would be interesting to look at government subsidies as a further development to understand how and whether government subsidies affect rent-seeking behaviour. Finally, due to the difficulty of obtaining actual case data, this study made reasonable assumptions on the parameters of the public sector-paid PPP projects based on project research. In future research, more data about the parameters need to be collected to verify the proposed model.

Data Availability

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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