Strategic Interaction Between the Government and the Private Sector in PPP Projects Incorporating the Fairness Preference

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ABSTRACT Due to factors including project uncertainties, contract incompleteness, and imperfect supervision systems, relying solely on contracts and supervision cannot effectively reduce opportunistic behavior in public-private partnership (PPP) projects. This study complements the existing literature by investigating the behavioral motivations behind strategic choices, an additional critical factor impacting the effectiveness and implementation of PPP contracts and supervision. Incorporating the fairness preference, this study applies an indirect evolutionary game theoretical approach to model the strategic interaction between the government and the private sector in a PPP project. Through the game theoretical and simulation analysis, possible evolutionary stable strategies (ESS) are predicted between the government and the private sector. The results indicate that the ESS highly depends on the private sector’s fairness preference. Private sector entities with weak fairness preferences tend not to behave opportunistically, while those with strong fairness preferences tend to be opportunistic. Moreover, the government adopts a supervision strategy for private sector entities with strong fairness preferences when the supervision cost is lower than the supervision benefit. These findings offer new insights for reducing opportunistic behavior and improving project performance in the context of PPP projects.

INDEX TERMS Fairness preference, indirect evolutionary game theory, opportunistic behavior, PPP project, government supervision.

I. INTRODUCTION

Opportunistic behavior is defined as a “behavior by a contractor that is motivated to pursue its self-interest with deceit to achieve gains at the expense of the owner” [8], [25]. In public-private partnership (PPP) projects, inconsistency of interests and information asymmetry between the government and the private sector are the main reasons for the private sector’s opportunistic behavior [3], [22], [31], which harms public interest and is a critical barrier to project success [23]. For example, in the PPP project of the Shuanggang Waste Incineration Power Plant in Tianjin, China, the private sector firm, to save costs and increase its own profit, did not thoroughly dispose of leftover materials in the waste incineration process, resulting in the release of a large amount of harmful gases, affecting the lives of the surrounding residents, and causing a severe negative social impact.

The literature discussing methods to reduce opportunistic behavior in PPP projects does so mostly from a contractual perspective; however, the results concerning how contracts affect opportunistic behavior remain inconsistent. Some scholars regard the contract as an effective way to attenuate opportunistic behaviors [25], [26]. On the contrary, other studies argue that contractual governance has no significant effect on opportunistic behavior [24], or may even lead to an erosion of positive attitudes and consequently more opportunistic behavior [17]. This inconsistency may be due to the uncertain and changeable environment of PPP projects [28], [39], as well as the project complexity and incompleteness of contracts [27]. Thus, although the PPP project contract is an important means to regulate the
behavior of both the government and the private sector, it is not enough to rely on the contract alone [27]. Other researchers claim that the opportunistic behavior of the private sector can be reduced through supervision [23], [35]. However, due to supervision costs and information asymmetry, in practice, supervision systems remain imperfect and fraught with problems such as inadequate capacity and flawed mechanisms. Therefore, it is difficult to reduce the private sector’s opportunistic behavior completely and effectively solely through contract and supervision. The literature largely neglects the importance of human behavioral motivation.

In practice, participants’ behavioral motivation can impact the effectiveness and implementation of contracts and supervision, and further influence the success of the PPP project. Thus, it is necessary to investigate the process by which both the government and private sector make behavioral strategic choices in PPP projects so as to reduce opportunistic behaviors and improve the cooperative relationship between the two parties. From this perspective, some literature discusses the long-term behavioral trends of both the private sector and the government by using the standard evolutionary game theory [14], [20], [23], [35], which is mainly based on the assumption that the entities are completely rational (material payoff maximizers). However, material payoff is not the only factor that determines people’s strategic choices; these studies neglect the behavioral preference of the private sector. To fill this gap, the present study uses the indirect evolutionary game approach to analyze the process of strategy selection for both the government and the private sector in PPP projects. As an extension of the standard evolutionary game, the indirect evolutionary game allows participants to choose strategies according to their preferences, rather than based on material payoffs alone [15], [16].

Many behavioral economists have highlighted that fairness is one of the critical factors that can impact people’s behavior and decisions [7], [11], [12], and the consideration of perceived fairness is a common phenomenon in practice [29]. In PPP projects, the private sector party is concerned with their own profits, but also takes an interest in the government’s revenue from the project, which affects their perception of the fairness of the profit distribution between the parties. For instance, when government project revenue is higher than the profit of the private sector party, the latter may perceive the profit distribution to be unfair, leading them to behave opportunistically (e.g., by cutting corners) to increase their profit and thus their perceived fairness of the profit distribution. Moreover, the traditional fairness preference model is based on an aversion to both advantage and disadvantage inequity of material payoffs [13]. However, in PPP projects, since the purpose of the private sector is to make a profit, the assumption that they are averse to advantage inequity is not in accordance with reality. Instead, the fairness preference, which assumes that the private sector dislikes disadvantage and prefers advantage in payoff inequity, is more realistic than a general payoff difference aversion preference.

Based on the above, this study assumes that the private sector has a fairness preference and analyzes the strategic interaction between government and the private sector in the contractual implementation stage. This study complements the literature on PPP projects, enables the government to better grasp the private sector’s opportunistic behavior, and formulates a more reasonable management strategy. First, we construct an indirect evolutionary game model between the government and the private sector. Then, the process of strategy selection and ESS are discussed through model solving, analysis, and simulation. The results show that the fairness preference of the private sector is one of the key factors determining the choice of strategies by both the government and the private sector.

The contributions of this study are twofold: Firstly, using indirect evolutionary game theory, this study explores the evolution of the long-term strategic interaction between the government and the private sector in a PPP project. Recent PPP literature mainly focuses on incentive mechanisms and partnership relationships using principal-agent theory and empirical research (see Section II for a literature review). Related evolutionary studies are based on the standard evolutionary game theory [14], [20], [23], [35] and do not take into account situations in which game participants choose strategies according to their behavioral preferences, or that the private sector has a fairness preference. By investigating how the government and private sector choose their strategies in PPP projects, as well as how the private sector’s fairness preference affects their long-term strategic choices, this study can provide a theoretical basis for the government to design appropriate management schemes in PPP projects.

Secondly, departing from the traditional fairness distributional preference of difference aversion [13], the present study considers the fairness preference, which assumes that entities dislike their payoffs to be lower and prefer their payoffs to be higher than those of others [6]. The aim of this study is to investigate how the strategic interaction between government and the private sector is affected by the fairness preference, and to provide suggestions to eliminate the negative influence of opportunistic behavior.

The rest of this paper is organized as follows. Section II presents a literature review. The model is presented in Section III. Section IV discusses the theoretical results and their implications. Following the theoretical analysis, Section V describes the system dynamic that is used to simulate the evolutionary process of the strategic interactions. Finally, Section VI concludes.

II. LITERATURE REVIEW

A. PARTNERSHIPS IN PPP PROJECTS

Partnership is one of the critical success factors of PPP projects [33] and is widely discussed in the literature. From the perspective of contract design, several studies have investigated how to design optimal incentive mechanisms to
balance the sharing of profit and risk between the government and the private sector. For instance, Wang and Liu [32] provided the optimal revenue-sharing ratio for PPP projects by considering the fairness preference of investors. Based on the theories of traditional principal-agent and reciprocal preference, Wang et al. [34] established an optimal incentive mechanism for PPP projects. They found that by setting different guarantee strategies for different participants, the government can utilize reciprocal preference to incentivize investors to exert more effort during a partnership and avoid moral hazard. Based on investors’ profitability outlooks, Wang et al. [37] established a game theory model to study the incentive mechanisms that can promote cooperation between investors and government.

Another stream of literature has investigated how to maintain the commitment and coordination between private and public organizations in long-term partnerships. For instance, through the case study of four PPP infrastructure projects, De Schepper et al. [10] demonstrated the relevance and importance of stakeholder inclusion in PPPs. Based on the analysis of a survey of PPP practitioners in the Netherlands, and using Consistent Partial Least Squares Modeling, Benítez-Avila et al. [4] empirically demonstrated the mediating role of relational norms and partners’ trust between contractual governance and partners’ contributions to project performance. Keers and van Fenema [18] studied how to maintain partnerships in PPP projects through risk management and developed a PPP projects risk management framework. Thorpe [30] studied PPP partnerships in the agricultural context and addressed how the public sector can make value chains work for smallholder farmers through PPPs, by not only improving economic coordination between farmers and their customers, but also by fostering procedural justice in value chain arrangements. Wang et al. [36] empirically investigated the interaction effect of the governance environment and private investment risk assumed by private partners; they found that the risk assumed by the private partner negatively influences private investment and that a higher level of governance can reduce this negative influence.

The literature reviewed in this section mainly concerns contract design and the long-term relationships between the government and the private sector in PPP projects, and is typically based on theoretical analyses and empirical evidence. Although some studies [32], [34] have considered social preferences, such as fairness preference and reciprocal preference, they focused mainly on the mechanism design. As mentioned earlier, our study contributes to this literature by incorporating the private sector’s fairness preference and investigating the strategic interaction between the government and the private sector, examining the process through which the government and the private sector choose their strategies.

**B. OPPORTUNISTIC BEHAVIOR IN PPP PROJECTS**

Some studies analyzed opportunistic behavior in PPP projects. Cruz and Marques [5] claimed that contract flexibility can reduce the possibility of opportunistic behavior in PPP projects. By using survey data on PPPs of the German Armed Forces, Lohmann and Rötzel [19] proved that aligning the objectives of the government and private investors can reduce opportunistic behaviors in renegotiations, thereby concluding that effective supervision could reduce opportunistic behavior in PPP projects. Xue et al. [38] investigated how transaction cost-related factors and elements of relational exchanges combine to form configurations that affect joint venture partners’ opportunistic behavior in the Chinese manufacturing sector. Liu et al. [21] provided an incentive mechanism to inhibit investors’ opportunistic tendencies in PPP projects and found that an increase in incentive intensity helps to lower the level of opportunistic behavior exhibited by investors. Next, Liu et al. [23] studied the strategic choice of opportunistic behavior during the operation of PPP projects by using evolutionary game theory. They found that there is no ESS between the government and the private sector, and that the results of the evolutionary game are related to the system’s initial state. Ning [28] empirically found that, in person-to-organization projects, quality performance ambiguity has a great impact on opportunistic behavior and contract application mediates this effect. Using empirical data on the Chinese construction industry, You et al. [39] found that opportunistic behavior is positively correlated with uncertainty. Moreover, contractual control and adaptation can weaken the effectiveness of uncertainty on opportunistic behavior, while contractual coordination can mitigate the opportunistic behavior induced by behavioral uncertainty.

The literature reviewed in this section theoretically and empirically studied opportunistic behaviors in PPP projects. Although some studies analyzed the behavioral interactions between government and the private sector by using evolutionary game theory [23], the literature assumed that both the government and the private sector only consider their own material payoffs when making decisions. The present study extends the literature by considering the private sector’s fairness preference and studying the process of strategy selection between government and the private sector. The results of this study can help governments better understand the nature of private sector opportunistic behavior, and formulate more reasonable supervision strategies and management schemes to reduce this behavior.

**III. HYPOTHESES AND MODELING**

In the process of PPP project implementation, the strategies of the government and private sector are changeable and will be affected by various factors. These strategies will achieve equilibrium after a dynamic adjustment process. In order to examine how the government and private sector choose their strategies in PPP projects, as well as how the private sector’s fairness preference affects their strategic choices, this study makes the following assumptions.

Assumption 1: Consider a PPP project with one government and one private sector entity. Assume that the government is a material payoff maximizer only concerned about
its own material payoff. The private sector has a preference for fairness and is concerned about both its own and the government’s material payoffs. In contrast to the traditional material payoff inequity aversion model of fairness preference [13], we assume that the private sector entity dislikes a disadvantage and prefers an advantage in inequity payoffs. We denote \( K (K \geq 0) \) as the private sector entity’s degree of preference for fairness; the higher the value of \( K \), the stronger the preference for fairness. In particular, \( K = 0 \) indicates that the entity is a material payoff maximizer concerned only about its own material payoff.

**Assumption 2:** We assume that the private sector entity chooses a “non-opportunistic” or an “opportunistic” strategy with a probability of \( x (0 \leq x \leq 1) \) and \( 1 - x \), respectively. Under the non-opportunistic strategy, the entity works hard and expends high levels of effort on the project. On the contrary, under the opportunistic strategy, the entity expends less effort on the project and engages in activities such as cutting corners by using cheaper materials.

When the private sector entity chooses an opportunistic strategy, the value of material profit that it can earn is denoted as \( R (R \geq 0) \); additionally, it can potentially obtain a non-material benefit denoted as \( R’ (R’ \geq 0) \), which includes a good reputation and opportunities to cooperate with the government in the future. Meanwhile, the government can obtain a benefit of \( G (G \geq 0) \) from factors including earning profits and increasing social welfare. We assume that the private sector entity would choose to behave opportunistically if and only if it could gain additional profits. Therefore, when the entity chooses to be opportunistic, in addition to profit \( R \), it could earn additional profit \( E (E \geq 0) \) through cost savings, government subsidies, and so on, while the government would lose benefit \( L (L \geq 0) \) through subsidies paid to the private sector, social reputation damage, and other factors.

**Assumption 3:** In the contract implementation stage, supervision is the major method of contractual governance. At this stage, the government can choose whether to supervise the private sector party in order to observe whether the latter acts in accordance with the contract. We assume the government chooses its strategies from “supervision” and “non-supervision” with probability \( y (0 \leq y \leq 1) \) and \( 1 - y \), respectively. When adopting a supervision strategy, the government expends supervision costs \( (C \geq 0) \) and the private sector’s opportunistic behavior will be observed with probability \( P \) \( (0 < P \leq 1) \). In the event that the opportunistic behavior is observed, the private sector party will receive a punishment with penalty \( B \) \( (B \geq 0) \). When the government chooses non-supervision, the supervision cost is 0 and the probability that the private sector’s opportunistic behavior will be observed is also 0.

Based on the above assumptions, the game payoff matrix between the government and private sector is shown in Table 1.

Based on Table 1, we can further obtain the replicator dynamic functions, \( F (x) \) and \( F (y) \), to represent the long-term change rule of the overall proportion of the private sector adopting a “non-opportunistic” strategy and the government adopting a “supervision” strategy, respectively, as follows:

\[
F (x) = \frac{dx}{dt} = x (1 - x) \left[ R’ - E - K (L + E) + yPB \right] \\
F (y) = \frac{dy}{dt} = y (1 - y) \left( PB - PBx - C \right)
\]

**IV. EVOLUTIONARY STABILITY ANALYSIS**

**A. EVOLUTIONARY STABILITY ANALYSIS OF PRIVATE SECTOR’S STRATEGIC ACTION**

According to Equation (1), the derivative of \( F(x) \) to \( x \) can be expressed as follows:

\[
F’ (x) = (1 - 2x) \left[ R’ - E - K (L + E) + yPB \right]
\]

Letting \( F’ (x) = 0 \), we obtain:

\[
x^* = 0, \quad y^* = \frac{E + K (L + E) - R’}{PB}
\]

According to the stability theorem of the replicator dynamic equation and the properties of evolutionary stability strategies, if \( x^* \) is the ESS, it should satisfy \( F (x^*) = 0 \) and \( F’ (x^*) < 0 \). Based on Equation (3), the results may be written as follows:

(1) When \( y = y^* = \frac{E + K (L + E) - R’}{PB} \) and \( 0 \leq \frac{E + K (L + E) - R’}{PB} \leq 1 \) \( (i.e., E + K (L + E) \leq PB + R’ \) for both \( x = 0 \) and \( x = 1 \) are stable, that is, there is no difference in result if the private sector chooses a “non-opportunistic” or an “opportunistic” strategy and hence, may choose either one of them.

(2) When \( y > y^* = \frac{E + K (L + E) - R’}{PB} \), then it can be shown that \( x = 1 \) is stable and the ESS is “Non-Opportunistic.” This result indicates that the possibility that the private sector chooses a “Non-Opportunistic” strategy increases with the increased probability of government supervision.

Furthermore, when \( E + K (L + E) < R’ \), we find that \( y^* < 0 \), that is, \( y > y^* \) holds for \( y \in [0, 1] \), and non-opportunism is the stable strategy for the private sector. It can be further concluded that increasing the potential benefits of the non-opportunistic \( (R’) \) strategy can reduce the private sector’s tendency to behave opportunistically.

(3) When \( y < y^* = \frac{E + K (L + E) - R’}{PB} \), \( x = 0 \) is stable and “opportunistic” is the ESS. In addition, it can be further concluded that, when \( E + K (L + E) > PB + R’ \), \( y^* > 1 \) and \( y < \)

| Private Sector | Supervision | Non-Supervision |
|----------------|-------------|-----------------|
| Non-Opportunistic \( (x) \) | \( R + R’ + KB (R - G) \), \( G - C \) | \( R + R’ + K (R - G) \), \( G \) |
| Opportunistic \( (1 - x) \) | \( R’ + E + K(R + E - G + L) - PB, \( G - L \) | \( R + E + K(R + E - G + L), \( G - L \) |

### Table 1. Me payoff matrix for government and private sector.
TABLE 2. Evolutionary stable strategies for the private sector.

| Conditions                                      | Non-opportunistic | Opportunistic |
|------------------------------------------------|-------------------|---------------|
| $E + K (L + E) < R'$                          |                   |               |
| $E + K (L + E) \leq PB + R'$                   |                   |               |
| $y^* > y'$, opportunistic                      |                   |               |
| $y^* > y'$, non-opportunistic                  |                   |               |
| $y^* = y'$, both                               |                   |               |

$y^*$ holds for $\forall y \in [0, 1]$, and the private sector entity’s optimal strategy is opportunistic. We can also find that increasing potential benefits of non-opportunistic behavior ($R'$) and punishment for opportunistic behavior ($B$) can reduce the private sector’s tendency to behave opportunistically.

The above results are summarized in Table 2. The positive utility that the private sector obtains from opportunistic behavior, which includes the utilities of both profit and fairness preference ($E + K (L + E)$), is the critical factor that influences its choice of strategy. The greater the positive utility value, the stronger the motivation for the private sector to behave opportunistically. Furthermore, the above analyses also indicate that when other conditions remain unchanged, increasing the private sector’s degree of preference for fairness, $K$, can enhance the positive utility of opportunistic behavior and further strengthen the private sector’s motivation to behave opportunistically. Therefore the private sector’s fairness preference affects its strategic choice. In addition, the private sector’s opportunistic behavior can be reduced by increasing penalties for such behavior ($B$) and the potential gains for non-opportunistic behavior ($R'$).

B. EVOLUTIONARY STABILITY ANALYSIS OF GOVERNMENT’S STRATEGIC ACTION

According to Equation (2), the derivative of $F(y)$ to $y$ can be expressed as

$$F'(y) = (1 - 2y) (PB - PBx - C).$$

Letting $F'(y) = 0$, $y^* = 1$, not $Cy^* = 1$:

$$y^* = 0, \quad Cy^* = 1, \quad x^* = \frac{PB - C}{PB}.$$  \[1\]

Similar to Section IV (A), we can further find that:

1. When $x = x^* = \frac{PB - C}{PB}$ and $PB \geq C$, both $y^* = 0$ and $y^* = 1$ are stable, that is, the ESS could be either “supervise” or “non-supervise.”

2. When $x > x^* = \frac{PB - C}{PB}$, then $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$, and $y = 0$ is stable, and “non-supervise” is the ESS. In addition, when $PB < C$, it can be derived that $x^* < 0$ and $x > x^*$ for $\forall x \in [0, C]$, that is, the government will choose a non-supervision strategy regardless of the value of $x$.

3. When $x < x^* = \frac{PB - C}{PB}$ and $PB > C$, then $y = 1$ is stable and “supervision” is the ESS.

Moreover, the supervision cost and benefit are the critical factors that influence the government’s strategic choice. When the supervision benefit (the expected penalty for the private sector’s opportunistic behaviors, $PB$) is lower than the supervision cost ($C$), the government tends not to supervise. On the contrary, when $PB \geq C$, then the government’s optimal strategy is related to the private sector’s probability, $x$, of choosing a non-opportunistic strategy. The higher the value of $x$, the weaker the government’s motivation to supervise. Contrary to the result of the pure strategy of the private sector, under no conditions would supervision be the only choice for the government, regardless of the private sector’s strategies.

C. EVOLUTIONARY STABILITY ANALYSIS OF MIXED STRATEGIES

Sections IV (A) and IV (B) discussed the ESS of the private sector and government, respectively. This section analyzes the evolutionary stability of their mixed strategies. In this game, there are five possible equilibrium points: $A (0, 0)$, $B (0, 1)$, $C (1, 0)$, $D (1, 1)$, and $E (x^*, y^*)$ herein, $x^* = \frac{PB - C}{PB}$, $y^* = \frac{E + K (L + E) - R'}{PB}$. According to [40], the stability of the equilibrium point of the evolutionary system can be obtained from the local stability analysis of the Jacobian matrix. The Jacobian matrix corresponding to Equations (1) and (2) can be expressed as:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix},$$

where,

$$\frac{\partial F(x)}{\partial x} = (1 - 2x) \left[ R' - E - K (L + E) + yPB \right],$$

$$\frac{\partial F(x)}{\partial y} = x (1 - x) PB,$$

$$\frac{\partial F(y)}{\partial x} = -y (1 - y) PB,$$

$$\frac{\partial F(y)}{\partial y} = (1 - 2y) (PB - PBx - C).$$

After further analysis, the matrix determinant, $det J$, and the matrix trajectory, $tr J$, are as follows:

$$det J = (1 - 2x) \left[ R' - E - K (L + E) + yPB \right] \times (1 - 2y) (PB - PBx - C) + x (1 - x) P^2 B^2 y (1 - y),$$

$$tr J = (1 - 2x) \left[ R' - E - K (L + E) + yPB \right] + (1 - 2y) (PB - PBx - C).$$

The stability analysis of equilibrium points is given in Table 3. In conjunction with Table 2, we discuss the following.

1. According to the stability analysis of the Jacobian matrix, when Equations (4) and (5) are valid (Friedman, 1991), the equilibrium $D (1, 1)$ can be the ESS.

$$det J (1, 1) = - \left[ R' + PB - E - K (L + E) \right] > 0 \quad \text{(4)}$$

$$tr J (1, 1) = - \left[ R' + PB - E - K (L + E) \right] + C < 0 \quad \text{(5)}$$
Since \( C > 0 \), Equation (4) holds under the condition \( R' + PB - E - K(L + E) < 0 \), which is obviously incompatible with Equation (4). Thus, Equations (3) and (4) cannot be valid and \( D(1, 1) \) is not the ESS, implying that when the private sector has a fairness preference, the strategy set of (Non-opportunistic, Non-supervise) cannot be achieved.

(2) According to the payoff matrix between the private sector and government in Table 1, there are four scenarios that need to be discussed.

**Scenario 1:** When \( PB < C \) and \( E + K(L + E) > R' \) (i.e., \( K \geq \frac{R' - E}{L + E} \)), the stabilities of the five possible equilibrium points are given in Table 4. In this case, \( A(0, 0) \), that is, (Opportunistic, Non-supervise), is the only ESS.

**Scenario 2:** When \( PB < C \) and \( E + K(L + E) < R' \) (i.e., \( K < \frac{R' - E}{L + E} \)), the stabilities of the five possible equilibrium points are given in Table 5. In this case, \( C(1, 0) \), that is, (Non-opportunistic, Non-supervise), is the only ESS.

**Scenario 3:** When \( PB > C \) and \( E + K(L + E) > R' + PB \) (i.e., \( K > \frac{R' + PB - E}{L + E} \)), the stabilities of the five possible equilibrium points are given in Table 6. In this case, \( B(0, 1) \), that is, (Opportunistic, Supervise), is the only ESS.

**Scenario 4:** When \( PB > C \) and \( E + K(L + E) < R' \) (i.e., \( K < \frac{R' - E}{L + E} \)), the stabilities of the five possible equilibrium points are given in Table 7. In this case, \( C(1, 0) \), that is, (Non-opportunistic, Non-supervise), is the only ESS.

The results of scenarios 1 to 4 are consistent with the results in Sections IV (A) and IV (B), whereby we can conclude that the degree of the private sector’s fairness preference, rather than the government’s supervision strategy, is the key factor affecting the former’s ESS. A private sector with a strong preference for fairness tends to behave opportunistically regardless of whether or not the government chooses to supervise (Scenarios 1 and 3). In contrast, a private sector with a weak preference for fairness tends to choose the non-opportunistic strategy of working hard and cooperating with the government; in turn, the government tends to not supervise the private sector even when the supervision benefit is higher than the supervision cost (Scenarios 2 and 4).

In addition, the threshold value of the private sector’s fairness preference degree, \( K \), is higher in scenario 3 than in other scenarios, which indicates that supervision is the government’s ESS if and only if the degree of the private sector’s fairness preference is very high (\( K > \frac{R' + PB - E}{L + E} > \frac{R' - E}{L + E} \)). This may be the case because the private sector is more likely to behave opportunistically when it has a strong fairness preference. In order to reduce this opportunistic tendency, the government should choose to supervise.

### D. SUMMARY AND DISCUSSION

From the above analysis, it can be concluded that the private sector’s fairness preference is the key factor that affects the strategic choices of both the government and the private sector. Moreover, a condition where a non-opportunistic private sector combined with government supervision can be the ESS does not exist. This indicates that the government’s supervision is not an efficient way to encourage the private sector to behave non-opportunistically, which is inconsistent with the results of the literature [19], [20].

In contrast to the studies concluding that the fairness preference is beneficial to team work and team performance...
our results find that the private sector’s fairness preference is not beneficial to project performance; conversely, it can increase the private sector’s tendency to behave opportunistically. Regardless of whether or not the government chooses the supervision strategy, the private sector’s degree of preference for fairness ($K$) is always the key factor affecting its ESS. When the private sector’s degree of preference for fairness is relatively low (high), its ESS would be non-opportunistic (opportunistic). This may be the case because, when the private sector entity has a strong preference for fairness, it will pay greater attention to the fairness of benefit distribution rather than the benefit itself. In order to ensure fairness, the private sector may take opportunistic actions to achieve a balance of benefits between the two parties. On the contrary, when the private sector has a weak fairness preference, it may be more concerned about the project’s overall benefit even at the expense of its own interests so as to ensure smooth project implementation. Therefore, it is better for the government to hire a private sector entity with a lower preference for fairness, which would be more beneficial in terms of reducing the supervision cost and promoting project performance. Moreover, from the threshold value of $K$, we can further conclude that, for a private sector entity with a high degree of preference for fairness, increasing its potential benefit from a non-opportunistic strategy ($R'$) would contribute to reducing its tendency to behave opportunistically.

The government’s ESS is determined by the supervision cost ($C$), expected supervision benefit (i.e., the expected penalty imposed on the private sector when supervised, $PB$), and the private sector’s fairness preference ($K$). Similar to the results of recent research [20], [23], the government is motivated to supervise only if the supervision benefit exceeds the supervision cost. Contrary to recent literature, however, when the private sector’s fairness preference is weak, the government would choose not to supervise even though the supervision benefit exceeds the supervision cost ($PB > C$). This may be the case as a private sector entity with a weak fairness preference tends not to behave opportunistically regardless of whether the government chooses to supervise or not. When the supervision benefit exceeds the supervision cost ($PB > C$), the government will choose to supervise only in the case where the private sector’s degree of fairness preference is very high ($K > \frac{R' + PB - E_L - E}{L - E}$).

V. SIMULATION ANALYSIS

A. SIMULATION ANALYSIS OF ESS FOR THE FOUR SCENARIOS

This section uses MATLAB to simulate the evolutionary path of the strategies adopted by the government and private sector under different parameters. Let the running time be 30 days, simulation step time be 0.05, and initial state of the system be $(X_0, Y_0) = (0.25, 0.75)$. The evolutionary paths of the strategies in scenarios 1 to 4 are shown in Figures 1 to 4, respectively.
both the private sector and the government. Figure 1 shows that when the private sector’s fairness preference is higher than a certain value, it will choose to behave opportunistically and the government will choose to not supervise. Contrary to Figure 1, Figure 2 shows that when the private sector’s fairness preference is low, it would choose to behave non-opportunistically, even though the initial tendency to behave non-opportunistically is low (i.e., X0 is low). Meanwhile, when the supervision cost exceeds the supervision benefit, the government would tend toward not supervising, which is similar to scenario 1 (Figure 1).

The evolutionary result in Figure 3 shows that when the supervision benefit can cover the supervision cost, the government will choose a supervision strategy to mitigate the loss from the opportunistic behavior of private sector entities with a high preference for fairness. Although, in this condition, the government’s initial supervision probability (Y0) is high, the private sector will continue to behave opportunistically because of the motivation of fairness. The simulation result in Figure 4 is the same as in Figure 2 (scenario 2), that is, a private sector entity with a weak fairness preference will not strive for benefit equivalence between itself and the government, and will tend to choose to behave non-opportunistically.

B. SIMULATION ANALYSIS OF PURE STRATEGY EVOLUTIONARY GAME

In this section, we investigate how the system’s initial state affects the evolutionary path and ESS. We take scenario 1 as an example. Based on Section V (A), let the initial states be (0, 0.8), (0.4, 0.1), (0.8, 0.5), and (0.9, 0.9), respectively. Figure 5 shows the evolutionary paths of both the private sector and the government. The results show that changing the initial state does not affect the evolutionary path of the final decision of either the government or the private sector, but would change the time taken for their evolutionary path to reach a stable state. The weaker the private sector’s initial willingness to behave opportunistically (X0 is high), the longer the time it takes to choose the opportunistic strategy. This indicates that reducing the private sector’s initial willingness to behave opportunistically can restrain its opportunistic behavior over short time periods. Similarly, when the initial probability of government supervision (Y0) is low, the evolutionary path to the stable state of non-supervision becomes shorter.

C. IMPACT OF THE PRIVATE SECTOR’S FAIRNESS PREFERENCE ON THE ESS

In order to further investigate the impact of the private sector’s fairness preference on the strategic interaction between the government and the private sector, this section discusses the influence of the value of $K$ on the system’s ESS. Consistent with Section V (A), let the system’s initial state be (0.25, 0.75). Based on Section V (B), we raise the value of $K$ from 0.2 to 0.5, and reduce it to 0; the resulting evolutionary paths of both the private sector and the government are shown in Figure 6. The results show that when $K$ is reduced to 0, the private sector would not be concerned about fairness and would choose to behave non-opportunistically to ensure the overall project benefit, which supports the results of scenario 2. When $K$ is increased to 0.5, the private sector’s strategy changes with a decrease in the time taken for its evolutionary path to reach a stable state. This indicates that, driven by stronger fairness motivation, the private sector will make opportunistic decisions more quickly to safeguard its own benefits.

In order to verify the impacts of the private sector’s fairness preferences on the strategy choices of both the private sector and the government in Section IV, we reset the system’s initial state to (0.8, 0.2) and increase the private sector’s fairness preference to a higher level. The evolutionary paths are shown in Figure 7. When the value of $K$ equals to 0.5, 1.5, and 3.5, respectively, the private sector’s willingness to adopt opportunistic behaviors becomes stronger, and the
time taken for the system to reach a stable state is reduced. Figure 7 also shows that, with increased time and interaction, the private sector will eventually choose to behave opportunistically no matter how strong its initial willingness to behave non-opportunistically is. However, under these conditions, since the private sector’s fairness preference is high, in order to reduce potential benefit losses, the government’s dominant strategy is to supervise, which supports the result of scenario 3.

VI. CONCLUSIONS AND PRACTICAL IMPLICATIONS

A. CONCLUSIONS
Understanding the strategic interactions between the government and the private sector can help to facilitate the implementation of PPP projects. By using indirect evolutionary game theory, this study investigates the ESS of both the government and the private sector under the condition that the private sector prefers fairness. Departing from the assumption of traditional fairness preference, however, we assume that the private sector dislikes disadvantage inequity and prefers advantage inequity in material payoffs. The results show that the private sector’s fairness preference is the critical factor that determines the ESS of both the government and the private sector.

Firstly, in contrast to existing studies that conclude that fairness preference improves work performance Akerlof & Kranton, 2005, Grund & Sliwaka, 2005, [32], this study shows that the higher the private sector’s preference for fairness in PPP projects, the more opportunistic it will be. Secondly, unlike existing studies, which conclude that supervision can encourage the private sector to expend more efforts in PPP projects and reduce opportunistic behavior [19], [20], this study finds that the private sector’s degree of preference for fairness is a key factor in determining its strategic choice, rather than government supervision. When the private sector entity strongly prefers fairness, it will choose to behave opportunistically regardless of whether the government chooses to supervise. On the contrary, when a private sector entity has a weak preference for fairness, it will not behave opportunistically even without government supervision. Lastly, similar to the results of recent studies [20], [23], we find that in PPP projects, supervision cost and supervision benefit are critical factors that determine the government’s supervision strategy choice. In cases where the supervision cost exceeds its benefits, the government tends to adopt a non-supervision strategy. However, deviating from the literature, in cases where the supervision cost is lower than its benefits, the government’s supervision strategy choice is determined by the degree to which the private sector prefers fairness; the government chooses to supervise only if the private sector has a very strong fairness preference.

B. PRACTICAL IMPLICATIONS
Based on the above theoretical results, we can provide practical suggestions for reducing the private sector’s opportunistic behavior and enhancing the performance of PPP projects. At the initial stage of PPP projects, choosing a private sector entity with a weak fairness preference is beneficial to project performance and could also save the government the supervision cost. However, fairness preference is difficult to observe; moreover, as the project progresses, the private sector’s fairness preference may change with the changing external environment. Therefore, in order to avoid the loss caused by opportunistic behavior, the government should pay greater attention to the private sector’s behavioral tendency during the project. Furthermore, the government may deter the private sector’s opportunistic behavior and avoid the loss arising from it by significantly increasing the potential benefit of the non-opportunistic strategy ($R'$), such as by offering further cooperation opportunities and enhancing the private sector’s social reputation, as well as by increasing the punishment for opportunistic behavior ($B'$). Lastly, government’s supervision is not always an efficient means of reducing the private sector’s opportunistic behavior. In order to save on supervision costs, the government can also strengthen the role of the public by encouraging the public to participate.
in the supervision of PPP projects, thereby supplementing government supervision and reducing the government’s cost.

C. LIMITATIONS AND FUTURE WORK

While this study complements the literature in the PPP area, it nonetheless has limitations. For instance, we only use a simulation method to test the theoretical results. In the future, case studies and empirical studies to validate the theoretical results can be considered. Additionally, we focus on the private sector’s fairness preference, but in practice the preferences of private sector entities may differ, and the government may also have behavioral preferences. Moreover, in practice, there are also cases where the government refuses to fulfill its contractual obligations and responsibilities; that is, the government may also be motivated to behave opportunistically. Future studies can further examine the strategic interaction in the case of private sector entities with heterogeneous preferences, as well as the case where both the government and the private sector have behavioral preferences.

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