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RISK DISTRIBUTION AND BENEFIT ANALYSIS OF PPP PROJECTS BASED ON PUBLIC PARTICIPATION

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Abstract. This paper aims to formulate a new PPP project public-participation mechanism that uses "public satisfaction" as a direct influencing factor in conjunction with the public-private benefit model to achieve a substantial response from project stakeholders regarding public satisfaction and ensure the transparency of PPP project operation. The proposed model, combined public satisfaction assessment with the principal-agent model, investigates the influence of public satisfaction on investors' efforts and the benefit or risk distribution between the government and private investors. The results show that the public's satisfaction level with the project directly affects the proportion of public and private income distribution, which provides a way for the public to directly play a substantive and positive role in PPP projects to guarantee public benefits and the smooth implementation. The increase in the public satisfaction evaluation of either the government or the investors, helps improve the overall effectiveness of PPP projects.

Keywords: public-private partnership projects, public participation, principal-agent theory, risk distribution, benefit analysis, project utility.

Introduction

The original intention of the government in promoting public-private partnership (PPP) schemes is to provide better public services and products for the public (Cui et al., 2018). As the ultimate consumers, the public's vital interests are directly related to the performance of the projects (Percoco, 2014). However, due to different goals and information asymmetry between the government and private investors, investors may engage in opportunistic behaviour to pursue self-interests, which harms projects and even results in group events (Liu et al., 2016). For instance, in 2014, the tap water of Lanzhou City in China was reported to have excessive benzene content, which was widely and strongly protested by the public. Then, Veolia, the investor in this PPP project, was questioned about the pollution. Likewise, in 2016, the waste incineration and power generation project in Tianjin City, was suspected of falsifying its environmental impact assessment (EIA). This event triggered a confrontation between the public and the construction party, seriously damaging the project. The occurrence of these incidents has not only aroused the public's doubts about PPP arrangements but also caused severe adverse social effects and undermined the government's credibility. By nature, one important reason for most project failures is that the project conflicts with the public interests (Xie et al., 2017).

From a theoretical perspective, since the public attributes of PPP products or services are non-competitive and non-exclusive and are mainly dictated by the government, PPP projects cannot be regulated through effective market mechanisms, resulting in "market failure". On the other hand, all governments bear the duty to supervise and manage PPP projects, while the roles of equity investment and supervision conflict exactly. Additionally, the over-indebtedness and limited resources of the government lead to "government failure". Consequently, public participation in the decision making and implementation of PPP projects is critical (Tam et al., 2009). More importantly, with the continuous development of global political democratization, the public has the right to participate in public management activities (Tam et al., 2009), thus improving the transparency of PPP projects to further supervise and constrain the behaviours of both the government and investors. Currently, the public has become an indispensable part of national governance, especially in project governance.

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Public participation refers to a range of activities that solicit citizen input on decision making among the elected leaders and on decision making among public administrators (Boyer et al., 2016). Different governments have various ways to encourage the public to participate in projects, such as public hearings (Kathlene & Martin, 1991), citizen panels, public meetings (Levine et al., 2005), and web-based forums (Brabham, 2010) etc. However, the public's rights are mainly limited to supervision, which overlaps to a large degree with the government's supervisory responsibility. In addition, the power of public participation in the project is finite, and the public's satisfaction can neither affect the revenues of governments and investors nor policy making (Laurian & Shaw, 2008; Li et al., 2012). That is, public satisfaction opinions are generally uncovered through questionnaires and are only an auxiliary means for the government to supervise projects but do not directly affect the improvement of public interests and social benefits. But fortunately, the evaluation methods of public satisfaction in PPP projects are mature nowadays. To prevent market failure and government failure, a reasonable and effective public participation mechanism for PPP projects must be formulated, substantially achieving public satisfaction and further affecting the decision making of both the government and private investors.

The essence of PPP schemes is the principal-agent relationship formed between the government and private investors. Therefore, the objective of this paper is to develop incentives to analyse the distribution of risks and benefits based on public satisfaction using principal-agent theory to inspire private investors to expend a great deal of efforts on cooperation. The findings will contribute new insights to the incentive mechanism and help to improve project governance efficiently in PPP projects. The rest of this paper is organized as follows. First, an overview of the previous research work in public participation in PPP projects is presented. Then, the model concerning the utility functions of the government and investors based on public satisfaction is constructed, followed by an optimal solution. Next, the results from this model are discussed. Specifically, a numerical simulation is illustrated, and the results of this simulation are examined to analyse the theoretical application of this model. Finally, the research closes by drawing certain conclusions.

1. Literature review

As the final recipients of public goods and services, the public is a third party, in addition to the public and private parties, which cannot be ignored (Torvinen & Ulkuniemi, 2016). Their attitudes and behaviours greatly affect the performance of PPP projects and should be paid full attention (Quick & Feldman, 2011). Due to the neglect of the public participation mechanism in some PPP projects, a series of social contradictions and conflicts occurred in the subsequent operation process (Huang et al., 2015). These events not only aroused public disputes to PPP schemes, but also caused serious adverse social impact and damaged to the government's credibility (Lang & Xu, 2013). Studies have shown that by increasing the public's awareness and scope of participation in PPP projects, optimizing and improving participation channels, and providing participation process guarantees, participation responsiveness, accountability mechanisms and support systems, the public's sense of identity with and responsibility for project planning can be enhanced to further improve the public's satisfaction with PPP projects (Jenkins-Smith et al., 2011; Kikuchi & Gerardo, 2009; Teo & Loosemore, 2014).

At present, many scholars have designed corresponding participation modes and main objects and also established a variety of framework mechanisms for public participation according to the different stages and natures of PPP projects (Torvinen & Ulkuniemi, 2016; Xie et al., 2014). For instance, PPP projects are supervised and managed based on laws, mainly through government inspection and supervision departments in China (Shan & Yai, 2011). Typically, PPP projects can be divided into six stages: project establishment, bidding, design, construction, operation, and handover. Among these stages, the project establishment and operation phases are the two stages with high public participation (Xie et al., 2017). In the initial stage of PPP projects, the public can ensure that their intentions are reflected in project decision making by means of public consultation, participation in community committees, network media, news media supervision and other forms (Neshkova & Guo, 2012); while in the operation stage, the public can score project engineering service quality, which reflects whether the service price is reasonable, to determine the level of public satisfaction and then urge relevant institutions to implement improvement measures (Boyer et al., 2016).

However, the mechanism of public participation in PPP projects only enables public discourse power to be unblocked; the evaluation of public satisfaction with projects still needs to be further discussed. Xie et al. (2017) conducted a systematic evaluation of key performance indicators used to benchmark participation performance in public construction projects in South China, then used linear and additional performance indexes to assess the satisfaction with public participation, and developed a public participation performance index of PPP projects. Torvinen and Ulkuniemi (2016) took a Finland PPP project in school property procurement as an example to establish a model for an end-user engagement process within innovative public procurement practices. The research revealed that the end-user's value potential not rest only with creating individual user value but also with increasing the public service's social, environmental and political value. Boyer et al. (2016) investigated the role and impact of public involvement in PPPs in the US transportation sector and addressed participatory mechanisms designed to ameliorate the public's engagement with decision makers around PPPs. The evaluation of public satisfaction regarding project implementation indicates the deepening and improvement of public participation mechanisms, which guarantees the improvement and quantification

of public participation under the premise of unimpeded public discourse power. The establishment of such public satisfaction evaluation index system and the measurement of public participation value help to promote the development and implementation of guaranteed PPP projects.

From the literature review, it can be concluded that existing studies mainly focus on two aspects: one is standardizing the content and policy recommendations of public participation in PPP projects, especially on improving the mechanism of public involvement; and the other is the evaluation of public participation, including a systematic construction of evaluation indicators and the evaluation methods for public satisfaction. However, these studies fail to provide a method through which the public can directly participate in and influence the interests of PPP parties to protect public benefits. Based on an evaluation results of the public's satisfaction with PPP projects, this paper uses 'public satisfaction' as a direct influencing factor in conjunction with the public-private benefit model. The analysis of the direct impact of the public's satisfaction on the risk distribution will provide a way for the public to directly play a substantive and positive role to guarantee public benefits and the smooth implementation of PPP projects.

2. Modelling and solutions

2.1. Principal-agent relationship between the government and investors

In the ideal PPP model, the government should pursue social public interests as the primary goal. However, on account of some performance factors such as attracting investment and completing indicators, the government may ignore public appeals or even make decisions that harm public interests (Liu et al., 2016). The private investors are assumed to be economic man following the market and will spare no effort to expand their own economic benefits during the cooperation (Brandts & Schram, 2001; Wang et al., 2018). When negotiating and consulting with the government, private investors may engage in rent seeking, concealing information and deceiving the government etc. (Wang & Liu, 2015). These investors are also motivated to reduce the cost of the operation and maintenance, thus damaging public interests and causing public losses (Lohmann & Rötzel, 2014). Therefore, as the public uses and finances projects, there is no doubt about the importance of public participation in PPP projects. To implement the right of public discourse and protect public interests in PPP projects, the level of public satisfaction with the project is considered in the income distribution model of public and private parties.

To investigate the returns of both the government and investors in PPP projects, the cooperative relationship between the two parties should be clarified first. Due to information asymmetry, the government cannot determine whether investors have chosen a great deal of efforts as the best strategy for their cooperation (Ni, 2012). Such information asymmetry leads to distrust between two sides and moral hazard. During the early operation stage of PPP projects, since investors are faced with the dilemma of high input cost and slow income growth, the government usually provides income guarantees (Buyukyoran & Gundes, 2018). Even if the investors may reduce the cost and market income, they still obtain stable income that is not less than that guaranteed by the government. Such speculation increases the proportion of government funds invested in a project, which is undoubtedly a waste of financial resources (Wang et al., 2018).

Principal-agent theory is often used to address the income distribution issue in the scenario with asymmetric information, which regards organizational management as how the principal can effectively motivate the agent to make the optimal action selection strategy (Guo & Wang, 2011; Ma & Zhang, 2014). By observing the agent's actions, external random factors and other information, the principal designs an appropriate income distribution mechanism to motivate the agent to implement the most favourable behaviour for the principal from the perspective of the agent's interests (Shrestha et al., 2013). In PPP projects, the government entrusts private investors to construct and operate the project through the franchise agreement, and then reclaims the project for free at the end of the franchise period (Keers & van Fenema, 2018). The project quality indeed not only affects the public's evaluation and satisfaction during the franchise period, but also directly determines the government's operation cost after the transfer (Robinson & Scott, 2009). The government, as the owner of the projects, perform a supervisory role as a principal; private investors, as the project executor, are held responsible for the implementation of the project and act as an agent (Muller & Turner, 2005).

2.2. Risk distribution and benefit analysis of PPP projects based on public participation

When participating in PPP projects, the public can score their satisfaction with the government and private investors (Boyer et al., 2016). Since the public is interested in the extent to which the social benefits of the projects are achieved, their evaluation of the projects affects incomes of both parties. Based on principal-agent theory, risk distribution model with public satisfaction assessment between the government and investors is constructed. Through model analysis, the impact of public satisfaction on investors' efforts, the benefit or risk distribution between the government and project operators, social benefits and other factors are investigated.

Assumption 1: Referring to the traditional H-M model with incentive mechanism (Holmstrom & Milgrom, 1987), private investors (i.e., the agent) pay effort a to produce π_r, which is simultaneously affected by a random factor θ. The factor θ obeys the normal distribution with zero mean and a variance σ^2, i.e., $\theta \sim N(0, \sigma^2)$. The actual production of the investors (π_r) can be expressed as follows:

$$\pi_r = a + \theta. \quad (1)$$

Assumption 2: The cost of the efforts expended by the investors $c(a)$ is:

$$c(a) = \frac{1}{2}ba^2, \quad (2)$$

where: b is the effort cost coefficient and $b > 0$.

Assumption 3: In order to encourage investors to participate in PPP projects, the government appropriately shares part of the income risk (Wang et al., 2018). Taking the transportation PPP project as an example, the expected return (π_e) to the investors is composed of the expected traffic volume (Q_e) multiplied by the average passage fee (P_0) of each vehicle, i.e., $\pi_e = Q_e \times P_0$. When the actual income of the projects (π_r) is lower than the average income of the industry, the government and investors jointly bear the market risk faced by the projects; that is, the government provides investors with certain guarantees (Hawas & Cifuentes, 2017). In this scenario, the difference between the expected return and the actual return is ($\pi_e - \pi_r$). For investors, the portion of the government's guarantee is the option value received (Kim et al., 2011). Similarly, the government does not bear all the income risks of the projects, so the option value acquired by the government is the part of the risk value assumed by the investors (Wang & Liu, 2015). Therefore, the option value obtained by the governments in the risk allocation is:

$$E_1 = (1-p)\times(\pi_e - \pi_r) = (1-p)\times(Q_e \times P_0 - a), \quad (3)$$

where: p represents the risk-sharing proportion of the government. Accordingly, investors' risk-sharing ratio is $1 - p$. The income of investors can be divided into two parts: the actual income obtained through their own efforts (π_r) and the value of the government guarantees $p\times(\pi_e - \pi_r)$. Then, the value obtained by the investors in PPP projects is:

$$E_2 = \pi_r + p\times(\pi_e - \pi_r) - c(a) = a + p(Q_e \times P_0 - a) - \frac{1}{2}ba^2. \quad (4)$$

Assumption 4: The government and investors can perceive each other's income gap, and this part of the difference impacts their utilities based on a public satisfaction evaluation. The utility functions of them are restricted by two factors: the public satisfaction evaluation and the responsibility of both parties to take risks. Typically, the public satisfaction factor has a cross-impact on the utilities of both parties, that is, the government's public satisfaction factor impacts investors' utility, while investors' public satisfaction factor affects the government's utility. On the one hand, the public satisfaction factor cross-functions in the utility functions to prevent the government or investors from using speculative means to obtain public satisfaction, thus interfering with the fairness of the evaluation results. On the other hand, the evaluation of public satisfaction with investors reflects the realization quality of the social benefits of PPP projects, and that with government affects the employed incentive measures for investors. Therefore, the public satisfaction factors act on two utility functions of both sides.

In the principal-agent model, the actual benefits to the principal and the agent are determined by the perception of fair risk distribution (Fehr & Schmidt, 1999; Tang & Wang, 2013). When investors acquire more value from the option than the government, i.e., $p\times(\pi_e - \pi_r) > (1-p)\times(\pi_e - \pi_r)$, the government assumes more project risks. According to the risk allocation principle that the party bearing a higher level of risks should also earn more project income (Ashuri et al., 2012), the option value difference between the investors and the government has an incremental utility on the utility function of the government. Along with the improvement of the public's satisfaction with investors, the added value also increases, which means that more risks assumed by the government can effectively improve the social benefits. In addition, for investors, the weak risk appetite may bring them a higher option value, but will have a negative effect on their utility function. With the improvement of the public's satisfaction evaluation of the government, the benefit reduction effect gradually increases. Therefore, the incentive mechanisms of the government and investors designed is reflected in the implementation of the public participation results in the risk or income distribution, thus guiding the relevant parties to pay more attention to the public evaluation. Additionally, the two parties should be encouraged to share project risks actively. Only when both of them have a strong willingness to cooperate will they be likely to maximize the economic and social benefits.

Based on the above analysis, the utility of the government and investors can be inferred respectively as follows:

$$U_1 = (1-p)(Q_e \times P_0 - a) + \delta_2\left[p(Q_e \times P_0 - a) - (1-p)(Q_e \times P_0 - a)\right]; \quad (5)$$

$$U_2 = a + p(Q_e \times P_0 - a) - \frac{1}{2}ba^2 + \delta_1\left[(1-p)(Q_e \times P_0 - a) - p(Q_e \times P_0 - a)\right], \quad (6)$$

where: δ_1 and δ_2 are the public's satisfaction evaluation of the government and the investors, respectively, $\delta_1 \in [0,1]$ and $\delta_2 \in [0,1]$. When the values of δ_1 and δ_2 are equal to 0, the public does not participate in a satisfaction assessment of either side.

In summary, the definitions of these relevant parameters are as follows in Table 1.

The government, as the principal of PPP projects, designs the risk distribution policy (p) based on public participation; in this scenario, private investors then determine the expanded level of efforts (a). Generally, the primary purpose of PPP schemes is to provide the public utility and infrastructure, and thus, the utility of the government should be maximized first. For investors, the efforts (a) are made based on the maximization of their own profits. Consequently, the principal-agent model can be designed as follows:

$$\max_p U_1 = \left\{\begin{array}{l}(1-p)(Q_e \times P_0 - a) + \\ \delta_2\left[p(Q_e \times P_0 - a) - (1-p)(Q_e \times P_0 - a)\right]\end{array}\right\}$$

Table 1. The definitions of the variables

Symbols	Definitions
a	The efforts expended by the investors
b ($b > 0$)	The cost coefficient for efforts expended by the investors
$c(a)$	The effort cost of the investors expended during the operation stage
$\theta\,(\theta \sim N(0,\sigma^2))$	A random variable of a normal distribution
π_r	The actual revenue of the investors
π_e	The estimated revenue of the investors
Q_e	The expected traffic volume
P_0	The average passage fee for each vehicle
p	The government's risk-sharing proportion
E_1	The option value obtained by the government
E_2	The option value obtained by the investors
$\delta_1\,(\delta_1 \in [0,1])$	The public's satisfaction evaluation of the government
$\delta_2\,(\delta_2 \in [0,1])$	The public's satisfaction evaluation of the investors
U_1	Government utility based on the public's satisfaction evaluation
U_2	Investor utility based on the public's satisfaction evaluation

$$U_2 = a + p\left(Q_e \times P_0 - a\right) - \frac{1}{2}ba^2 + \delta_1\left[\left(1-p\right)\left(Q_e \times P_0 - a\right) - p\left(Q_e \times P_0 - a\right)\right] \geq x_0; \quad \text{s.t. (IR)}$$

$$\max_a U_2 = a + p\left(Q_e \times P_0 - a\right) - \frac{1}{2}ba^2 + \delta_1\left[\left(1-p\right)\left(Q_e \times P_0 - a\right) - p\left(Q_e \times P_0 - a\right)\right]; \quad \text{s.t. (IC)}$$

$$a^* = \frac{p(2\delta_1 - 1) + 1 - \delta_1}{b}, \quad \text{s.t. (IC')}$$

where: x_0 represents the reservation utility that is the maximum expected utility obtained under other market opportunities. (IR) refers to the participation constraint of investors, implying that the expected utility U_2 under the PPP contract is no less than the reservation utility x_0. (IC) is the set of incentive compatibility constraint to maximize self-interests. And (IC') is the first-order equivalent condition of (IC), signifying the optimal and the maximum efforts invested by private investors as a given risk distribution policy provided by the government. As a result, the optimal guarantee ratio p^* and investors' optimal effort selection a^* are calculated as follows:

$$a^* = \frac{Q_e \times P_0}{2} + \frac{\left(2\delta_1 - 1\right)\left(\delta_2 - 1\right)}{2b\left(2\delta_2 - 1\right)}; \quad (7)$$

$$p^* = \frac{\left(2\delta_2 - 1\right)\left(b \times Q_e \times P_0 + \delta_1 - 1\right) + \left(2\delta_1 - 1\right)\left(\delta_2 - 1\right)}{2\left(2\delta_1 - 1\right)\left(2\delta_2 - 1\right)}. \quad (8)$$

3. Model analysis and discussions

In PPP projects with public participation proposed above, the government's incentive effects on investors (i.e. a^*) is positively related to the public's evaluation of the government (δ_1). However, in current practice, the results of public satisfaction evaluations regarding the project mostly come from evaluations of the convenience and comfort of the project use etc., so there is a case that the public only conducts unilateral evaluations of the government or investors. Many PPP projects lack public participation mechanisms; that is, the public does not participate in the construction, completion and use of the project. In order to compare the incentive effects of the risk sharing mechanism provided by the government on investors, some special scenarios are discussed. When the public does not participate in PPP project supervision and evaluation, namely, $\delta_1 = 0$ and $\delta_2 = 0$, the investors expend the least efforts, i.e. $a^* = \frac{b\pi_e - 1}{2b}$. When investors receive a large number of public evaluations, that is, $\delta_2 = 1$, regardless of the government's chosen system (e.g., $\delta_1 = 0$ and $\delta_1 = 1$), investors will invest a fixed amount of efforts, i.e. $a^* = \frac{\pi_e}{2}$. If $\delta_1 = 1$ and $\delta_2 = 0$, the investors will pay the greatest efforts $a^* = \frac{b\pi_e + 1}{2b}$. To achieve greater cooperation, the government must set an appropriate restraint mechanism. As the manager, the government cannot expect investors to show spontaneous goodwill. Instead, the government should create the necessary internal and external environments to advance cooperation. When the public's evaluation of investors is high and does not participate in the supervision of the government, the investors' social responsibility is greater. In contrast, when the public only participates in government supervision and does not evaluate the performance level of the investors, the government assumes greater social responsibility.

Based on the influence of the public satisfaction with the government and investors on their behaviours, the effect of public evaluation on the investors' chosen level of efforts, the amount of risk distribution and the utility function are analysed as follows.

Proposition 1: The amount of risk-taking by the government does not always increase with the improvement of the public evaluation. When cooperating with willing investors, the government's the rate of risk taking is closely related to the public satisfaction. Moreover, the risk ratio taken by the government improves with the increased public evaluation of investors.

Prove: $\frac{\partial p^*}{\partial \delta_1} = \frac{1 - 2b\pi_e}{2(2\delta_1 - 1)^2}$, $\frac{\partial p^*}{\partial \delta_2} = \frac{1}{2\left(2\delta_1 - 1\right)^2} > 0$.

Thus, when $b\pi_e > \frac{1}{2}$, then $\frac{\partial p^*}{\partial \delta_1} < 0$. The proportion of

risk allocation is negatively correlated with the government's public evaluation. For different values of $b\pi_e$, the relationships of the proportion of risk allocation and public evaluation between the government and investors are shown in Figures 1 to 3.

Figure 1 depicts the relationship among p^*, δ_1 and δ_2. A higher expected return on investment (π_e) means that the government may need to provide a higher guarantee value, which reflects poorly on the government. Therefore, an increase in the government's public evaluation is accompanied by higher risks that investors must bear. However, there are two unique areas in the figure: when $\delta_1 \in (0.5,1)$ and $\delta_2 \in (0,0.5)$, and when $\delta_1 \in (0,0.5)$ and $\delta_2 \in (0.5,1)$, the government's risk ratios are 1 and 0, respectively. When working with an investor with a lower public satisfaction rating, the government establishes an attractive guarantee system to effectively improve service quality. In contrast, investors are eager to participate in the government's projects, even when the government's public evaluation rating is low. To obtain a higher expected income, investors opt for high risks.

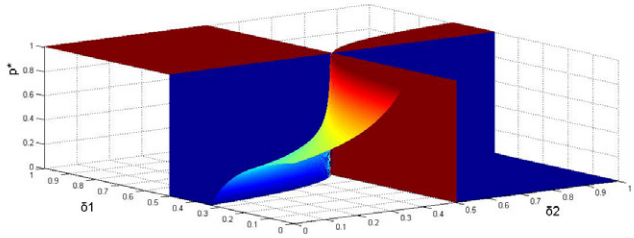

Figure 1. When $b\pi_e > \frac{1}{2}$, the relationship between p^* and δ_1, δ_2

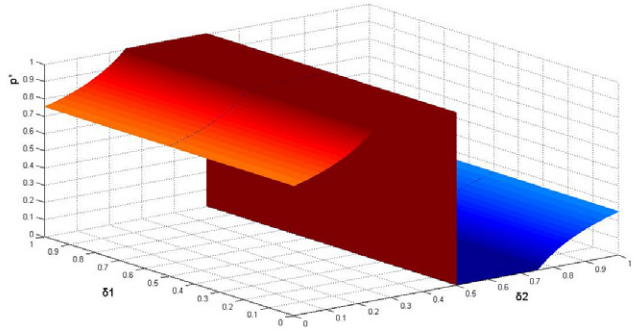

Figure 2. When $b\pi_e = \frac{1}{2}$, the relationship between p^* and δ_1, δ_2

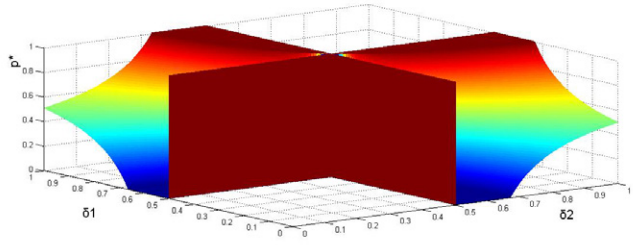

Figure 3. When $b\pi_e < \frac{1}{2}$, the relationship between p^* and δ_1, δ_2

When $b\pi_e = \frac{1}{2}$, $\frac{\partial p^*}{\partial \delta_1} = 0$. Thus, the proportion of risk allocation is not affected by the government's public evaluation. As shown in Figure 2, when the investors' established income value or cost is constant, the government's public evaluation no longer affects the risk allocation ratio. Investors with high public satisfaction ratings bear more risks.

When $b\pi_e < \frac{1}{2}$, then $\frac{\partial p^*}{\partial \delta_1} > 0$; i.e., when $\pi_e < \frac{1}{2b}$, the expected income of investors (π_e) is controlled within the acceptable range of the government, so investors generally have a strong willingness to cooperate with the government to complete the project construction. As the government notices the increase in investors' public evaluations, the government's eagerness to collaborate becomes apparent. In this case, based on the public evaluation, the government expresses a desire to bear more risks in response to investors' goodwill. Figure 3 demonstrates the relationship among p^*, δ_1 and δ_2 when $b\pi_e < \frac{1}{2}$. As mentioned above, when investors express a willingness to cooperate, the government appropriately rewards them; that is, when the public evaluation rating of the government increases, so does the amount of the guarantee provided to the investors.

Taken altogether, the government should establish a flexible incentive mechanism when cooperating with different types of investors. In the traditional determination of the risk allocation ratio for PPP projects, both the government and investors should pay more attention to investors' earning capacity, project market conditions and other factors, while ignore the importance of public evaluation on the impact of the allocation ratio. For the government, to achieve the best incentive effect and effectively promote the smooth development of PPP projects, timely designing attractive incentive policies combined with public satisfaction evaluations is essential. In terms of investors to obtain high returns in PPP projects, they need to perform a good job and achieve a high satisfaction rating from the public. And this process of expending efforts will also bring increased social benefits.

Proposition 2: The effort level of investors that is expended during project cooperation does not always increase with increases in the public's evaluation of them or the government.

Prove: $\frac{\partial a^*}{\partial \delta_1} = \frac{\delta_2 - 1}{2\delta_2 - 1}$, $\frac{\partial a^*}{\partial \delta_2} = \frac{2\delta_1 - 1}{2b(2\delta_2 - 1)^2}$. When $0 \le \delta_2 < \frac{1}{2}$, $\frac{\partial a^*}{\partial \delta_1} > 0$; if $\frac{1}{2} < \delta_2 < 1$, $\frac{\partial a^*}{\partial \delta_1} < 0$. Likewise, when $0 \le \delta_1 < \frac{1}{2}$, $\frac{\partial a^*}{\partial \delta_2} < 0$; if $\frac{1}{2} < \delta_1 < 1$, then $\frac{\partial a^*}{\partial \delta_2} > 0$

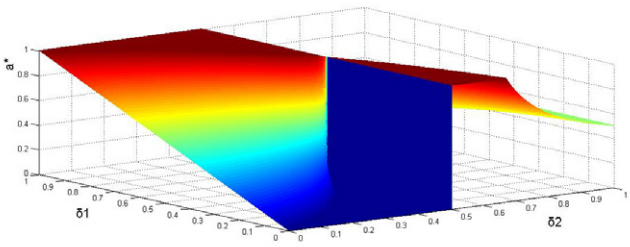

Figure 4. The relationship between a^* and δ_1, δ_2

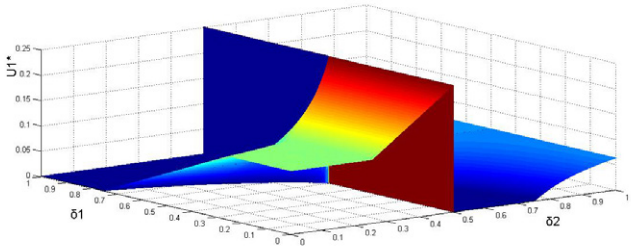

Figure 5. The relationship between U_1^* and δ_1, δ_2

(Figure 4). To identify effective incentives, blindly improving the intensity of rewards and punishments is not a wise choice for different investors. When the public evaluation of investors is low, the government can increase the intensity of the rewards and punishments to improve investors' efforts. When investors' public satisfaction rating is high, setting up a strict punishment system is likely to diminish investors' enthusiasm, resulting in reduced efforts conversely. Investors with high public evaluations expend greater efforts under the government's high reward system.

Both the government and the public expect investors to invest great efforts in PPP projects. It should be noted that the efforts of investors are affected by the public's satisfaction with the government and investors. The government should ensure the performance of their duties and obtain the public's recognition of its work first. On this basis, as the public's satisfaction with the service quality increases, the efforts of the investors also improve.

Proposition 3: An increase in the public evaluation of the government and investors does not always increase their utility values, and the utility effects of δ_1 and δ_2 are similar. When the government achieves a high public level satisfaction and the investors' public evaluation level is low, the government prefers to sacrifice their own benefits to punish non-cooperative behaviours. As displayed in Figure 5, when $\delta_1 \in (0.5,1)$ and $\delta_2 \in (0,0.5)$, the principal's utility is close to 0. In the case of investors, when δ_1 and δ_2 are in the interval (0, 0.5), the government's public evaluation is fixed, and the investors' utility improves with the increase in their public evaluation. If the public evaluation of investors is fixed, the utility improves with the decline in the government's public evaluation. When the public satisfaction with investors is high, utility increases with the increase in the government's public evaluation.

Public satisfaction with PPP projects is affected by many factors, such as project service quality, operation and management level, service price and public income level. If the public is satisfied with the project, their trust in the project will increase, and project efficiency improves eventually. However, it is important to note that the improvement in public satisfaction is for both government departments and investors, and a large gap between the two adversely affects the realization of the social benefits of the project.

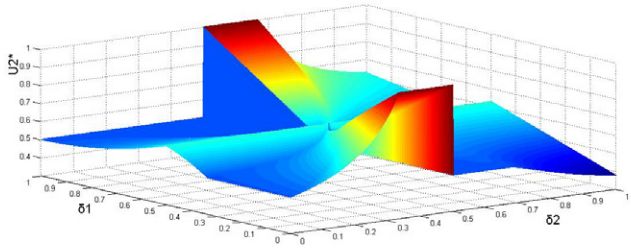

Figure 6. The relationship between U_2^* and δ_1, δ_2

From Figure 6, the lowest point of investors' utility value is $\delta_1 = 1$, $\delta_2 = 0$, and $\delta_1 = 0$, $\delta_2 = 1$, which means that a collaboration is unlikely to be successful if only the principal or the agent receives high public evaluations. This part of the simulation is a supplement to Proposition 1. If the public only participates in the evaluation of the satisfaction of the government or investors, this can easily lead to incomplete evaluation conclusions, affecting reliability. In other words, if the public is only satisfied with the work of the government but completely unsatisfied with the work of the investors, or if the public is completely satisfied with the efforts of the investors but dissatisfied with the government's efforts, this affects the smooth progress of the project, resulting in zero project benefits. Therefore, this part of the conclusion once again emphasises the importance of the cooperative efforts between the government and investors. Only when the public's evaluation of both sides reaches a balanced range can it be beneficial to maximize the social and economic benefits of PPP projects.

4. Numerical example

To describe the model more intuitively and verify its effectiveness, the relevant parameters are assigned as shown in Table 1. The expected income and the cost coefficient have direct impacts on the risk-sharing rate, investors' efforts and mutual income. Therefore, the assignment for $b\pi_e$ is divided into two categories: one product of $b\pi_e$ is greater than 0.5 and the other is less than 0.5.

When the public evaluation of investors is fixed, the influence of the government's public satisfaction

rating on the parameters is examined. The scenario 1 shows that the government considers investors' evaluation scores to be too low to cooperate when the public evaluation of investors is 0.2. Thus, the government increases the penalty for investors, which increases their own evaluation result (i.e., from 0.1 to 0.4). The effort of investors (from a negative value to 0.37) improves under the penalty mechanism.

From scenario 2, when the public evaluation of investors is far higher than that of the government, investors assume all the project's risks. Although the increase in the government's public evaluation rating (from 0.1 to 0.4) increases the utility value of investors, it does not encourage investors to expand their efforts or even reverses the impact (from 0.63 to 0.53) because, in the case of investors taking all the risks, with the increase in government guarantees, investors obtain the same return and improve their own benefits with minimal efforts. However, it is gratifying that although the efforts of investors decrease, the incomes of both parties and overall project improve. With the increased public satisfaction rating of the government, the overall income of the project grows from 0.54 to 0.67. Consequently, when working with investors with good public evaluations, an increase in the government's public satisfaction helps improve the project's income.

Based on a comparison of the data in scenarios 3 and 4, when the government's satisfaction rating is high (e.g., 0.8), the relative risk to borne by the government is also high, or the government assumes full responsibility for the project's risks. Investors' efforts do not always reflect their public evaluations. When the government's public evaluation is low (e.g., 0.2), investors' efforts decrease (from 0.16 to –0.04) with the increase in their evaluation score (from 0.1 to 0.4) because the increase in the investors' public evaluation is sensitive to the government's rewards and punishments. Moreover, when investors find that the government's rewards and punishments are weak, they feel dissatisfied and then reduce their efforts. It is worth noting that a high public evaluation of the government does not yield high benefits to the government or the project. Compared to scenario 4, the utility value of the government and project in scenario 3 is higher, which suggests that the government's high incentive policy may be more appealing in the early stages of the project. However, the guarantee or risk exceeds the budget, and hence, a high incentive policy does not actually yield more benefits for the project or the public.

Four unique public evaluations are simulated in scenario 5. When both the government and investors receive high public evaluation scores, the overall benefit of the

Table 2. Numerical simulation

Scenarios	b	π_e	δ_1	δ_2	p^*	a^*	U_1	U_2	$U_1 + U_2$
1	1	1	0.10	0.20	0.60	–0.03	0.45	0.57	1
			0.20		0.50	0.10	0.45	0.55	1
			0.30		0.29	0.23	0.48	0.53	1
			0.40		0	0.37	0.51	0.55	1.06
2	1	1	0.10	0.80	0	0.63	0.07	0.47	0.54
			0.20		0	0.60	0.08	0.50	0.58
			0.30		0	0.57	0.09	0.54	0.62
			0.40		0	0.53	0.09	0.58	0.67
3	1	1	0.20	0.10	0.40	0.16	0.49	0.52	1
				0.20	0.50	0.10	0.45	0.55	1
				0.30	0.71	–0.02	0.43	0.62	1.04
				0.40	1	–0.40	0.56	0.64	1.20
4	1	1	0.80	0.10	1	0.84	0.02	0.52	0.54
				0.20	1	0.90	0.02	0.52	0.54
				0.30	1	1.03	–0.01	0.49	0.49
				0.40	1	1.40	–0.16	0.34	0.18
5	1	1	0	0	0.50	0	0.50	0.50	1
			0	1	0	0.50	0	0.38	0.38
			1	1	0.50	0.50	0.25	0.63	0.88
			1	0	1	1	0	0.50	0.50
6	0.5	0.6	0.10	0.70	0	0.60	0	0.42	0.42
			0.20		0.04	0.53	0.02	0.40	0.43
			0.30		0.13	0.45	0.05	0.40	0.45
			0.40		0.38	0.38	0.10	0.41	0.51

project is the highest. Scenario 6 examines the effect of the public evaluation of project participants on the parameters when the product of $b\pi_e$ is less than 0.5. When the public evaluation of investors is fixed and the government's public satisfaction rating increases, the portion of risk taking assumed by the government, the efforts of investors, and the change in utility between the government and investors are all similar to those in scenario 3, excluding the project's income.

By comparing the changes in the project's benefits using six scenarios, the closer the public evaluation coefficients of the government and investors are, the higher the project's utility. When selecting private investors, the government should examine investors' public evaluations from past projects in which they participated and choose the most suitable partner to complete the project. According to the rightmost column in Table 2, the overall utility of the project increases with the increase in public satisfaction with the government or investors in scenarios 1, 3, 4 and 6.

Conclusions

PPP projects are generally large-scale public infrastructure projects that involve not only the distribution of interests between the government and private investors but also the interests of the public (Tam et al., 2009). Therefore, the performance of PPP projects has a high social effect, which is related to the authority and integrity of the government (Huang et al., 2015). In the absence of public participation as a third-party guarantee, it is easy for the government and investors to confront each other when making decisions: to avoid monopolistic management of urban infrastructure, the government wants more control over projects, while investors are worried that the government will break its promise and ask for a higher guarantee (Shan & Yai, 2011). Therefore, the two sides often conduct multiple negotiations to resolve differences, which reduces the efficiency of cooperation and even leads to the failure of the projects and affects the public interests (Xie et al., 2017).

In PPP projects, a long concession period means private investors face changes in various external economic environments, such as road flow, interest rate, inflation rate and other macroeconomic conditions (Li et al., 2005). Taking the PPP transportation project as an example, under the condition of a fixed rate, road flow becomes a risk that investors have to face, which has a direct impact on their income (de Albornoz & Soliño, 2014). To attract private investors to participate in the infrastructure projects and guarantee the normal operation and maintenance of investors in the presence of market risks, the government usually shares the risk with private investors by providing guarantees (Wang et al., 2018). Based on the hypothesis of the economic man, the investors in PPP projects will always focus on their own self-interests rather than public benefits. In the absence of a reliable supervision mechanism, the government officials may even engage in "rent-seeking" behaviours, leading to project corruption and further damaging public interests (Takano, 2017). Public participation can be an important component of PPP project supervision systems and effectively resist project corruption (Boyer et al., 2016).

Therefore, as one of the stakeholders in PPP projects, the public should play a role in the project, and their interests are the starting point for public participation. To ensure the effectiveness of public participation in the decision making or implementation of PPP projects, public satisfaction evaluations should be included in the income or risk allocation model and directly influence the proportion of the income distribution between the government and private investors, motivating the private sector to pay more attention to project quality and projects. Social benefits, thereby increasing the public discourse on PPP projects, provide a new incentive path for the government to guarantee the social and economic benefits of PPP projects. In the process of PPP project guarantee option value allocation, the project participants' perceptions of whether the distribution result is reasonable is not only based on their own risk-taking ability but also on the amount of risk assumed by other participants, which affects their level of satisfaction. For instance, faced with investors' low public satisfaction ratings, the government needs to increase incentives and punishments. In contrast, investors with high public satisfaction ratings are discouraged from cooperating if the punishment intensity is too severe. With the increase in public satisfaction for either the government or the investors, the overall effectiveness of the project is improved. However, when the government satisfaction rating is high and the investor satisfaction rating is low, the project utility value decreases instead. As a result, the government's effective incentive policy means adopting a differentiated incentive model for different cooperative units. Finally, a limitation should be highlighted. Since it is difficult to test the theoretical conclusions by using real cases as a result of a lack of data, only a numerical simulation is presented. Nevertheless, how to comprehend the parameters have been explained, helping to guide both governments and private investors to choose the optimal strategies in PPP projects.

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Author contributions

Yinglin Wang conceived the study and was responsible for the research design and methodology. Ruolan Gao was responsible for the model development and numerical example. Yinglin Wang developed the data analysis and the conclusion.

Disclosure statement

The authors declare that they have no competing financial, professional, or personal interests from other parties.

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