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ATTRACTING PRIVATE INVESTMENT IN PUBLIC-PRIVATE-PARTNERSHIP: TAX REDUCTION OR RISK SHARING

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Abstract. With the financial burden of government increasing, the Public-Private-Partnership (PPP) model has become an alternative method to develop public infrastructure. To efficiently promote the private sector to participate in PPP, making a proper incentive policy is critical for the government. This paper examined the effects of two governmental support policies, i.e., tax reduction and risk-sharing, on the investment decision of the private sector, and further compared the relative efficacy of these two policies. The results manifest that: first, both tax reduction and risk-sharing policies motivate private sector to invest earlier; second, although the capital structure decision of the private sector is free from the influence of the risk-sharing policy, the optimal debt level under tax reduction policy shows a U-shape relationship with the incentive ratio; third, when completion risk is large, there exists efficiency loss for total benefits of the project under the risk-sharing incentive policy. Besides, the efficacy of two incentive policies varies depending on the scenario. Firstly, given the same incentive ratio, the risk-sharing policy proves to be more effective than the tax reduction policy. Secondly, when considering the same level of incentive loss for government, tax reduction policy outperforms than risk-sharing policy in terms of efficacy. Thirdly, the efficacy of these policies also depends on the completion risk level: under small completion risk, risk-sharing policy is more effective, whereas under large completion risk, the tax reduction policy takes precedence. Based on these findings, some managerial insights that could assist government in formulating more effective incentive policies are proposed.

Keywords: PPP, tax reduction, risk-sharing, investment decision, capital structure, efficacy.

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1. Introduction

Over the past decades, with the financial burden on governments worldwide increasing, the Public-Private Partnership (PPP) model has become increasingly popular in the field of public infrastructure development (Geng et al., 2020; Guan et al., 2018; Guo et al., 2024; Wang et al., 2021). In PPP projects, it is primarily the private sector that is responsible for the financing, construction, and operation of projects (Delmon, 2021; Geng et al., 2023b; Wang et al., 2018b, 2023b). Compared to traditional government procurement, this innovative project delivery method largely decreases financial burden on governments and bring more advanced managerial and technical experience from the private sectors to the infrastructure development (Geng et al., 2022; Song et al., 2018; Zhang & Liu, 2022). The World Bank dataset finds that private participation in infrastructure commitments reached $36.4 billion in 44 countries in the first half of 2023, with a surge in the number of projects to 161 (The World Bank, 2023). However, due to the substantial investment required for infrastructure and various unforeseen risks, a PPP project may not be viable from the private sector's perspective (Akomea-Frimpong et al., 2021; Cherkos et al., 2020; Kukah et al., 2024). For example, Asian Development Bank (2024) found that the private sector will not invest in PPPs, unless there are well-prepared and properly structured projects with fair risk allocation. This situation was even worse during the COVID-19 crisis, where the private investment amount experienced a sharp decline in 2020 (The World Bank, 2021). In this case, the governments may consider providing the private sector support policies, such as subsidies and guarantees (Feng et al., 2023; Li et al., 2023; Soumaré, 2016). However, to formulate more effective incentive policy, two practical questions need to be addressed: (1) How does the incentive policies influence the investment decisions of the private sector? and (2) Which incentive policy is more effective in encouraging the private sector to invest in PPP projects?

Generally, the government promises to offer tax benefits of the project to the private sector with the tax reduction policy, e.g., tax revenue recycling scheme (Liu et al., 2023; Wang et al., 2022; Yang et al., 2023); and to compensate a share of construction cost to the private sector in case of completion risk happening with the risk-sharing policy (Li & Wang, 2023; Mukherji, 2023; Shi et al., 2023; Tallaki & Bracci, 2021). Out of this objective, this study explores how these two government support policies, i.e., the tax reduction policy and risk-sharing policy, influence the investment decision of the private sector, and investigates which policy is more effective. By examining the effects of these two popular governmental policies, our research mainly finds that: (1) Both policies increase the competition in the infrastructure market, which reduces the waiting option value of the private sector and encourages earlier investment. (2) The risk-sharing policy does not affect the capital structure decision of the private sector. Conversely, under tax reduction policy, the optimal debt level exhibits a U-shaped relationship with the tax reduction ratio, and the default boundary for the private sector decreases as the tax reduction ratio increases. (3) The efficacy of two incentive policies varies depending on the scenario. Notably, the risk-sharing policy is more effective in encouraging private sector investment under the same incentive ratio scenario, whereas the tax reduction policy is more effective under scenarios where there is the same incentive loss for the government. (4) Additionally, when completion risk is large, the risk-sharing policy leads to efficiency loss in project benefits.

The contributions of this study are twofold. Practically, it offers managerial insights that could aid governments in developing more effective incentive policies for PPPs. For instance, when the government's incentive loss is predetermined or the completion risk is large, priority should be given to the tax reduction incentive policy. Conversely, if the incentive ratio is fixed and the completion risk of the project is relatively small, the risk-sharing incentive policy should be considered first. Theoretically, this study acts as a solid foundation for knowledge development in the field of attracting private investment in PPP projects.

The rest of this study is organized as follows: In the second section, a thorough literature review is presented, and the research gap is digged out. The third section outlines the methodology utilized in this study. In the fourth section, a benchmark scenario is set up to analyse investment decisions of private sector without governmental incentives. Then the impact of government's tax reduction policy and risk-sharing policy is examined in the fifth and the sixth section. a comparison of the relative efficacy of the two government support policies is also included. In the seventh section, a numerical analysis is displayed to verify the propositions in the preceding sections. Finally, the conclusion and various implications are given out in the eighth section.

2. Literature review

Our research engages with three main streams of relevant literatures. The first one focuses on evaluating of government support policies in PPP projects. The second stream examines how government support policy influence the investment behaviour of the private sector in PPP projects. Lastly, the third stream explores the relative efficacy of government support policies to promote and speed up private investment.

2.1. Evaluation of government support policy in PPP projects

Government support policies enhance the feasibility of PPP projects (Cui et al., 2018; Debela, 2022; Jin et al., 2020; Rohman, 2022; Wang et al., 2023a; Xu, 2023). Scholars have evaluated their economic value using various methods and from different perspectives. For example, Brandao and Saraiva (2008) utilised real option theory to evaluate the minimum traffic guarantee in infrastructure PPPs. They discovered that high-risk PPP projects can become financially viable by incorporating such guarantees. Building on this foundation, they further concluded that minimum demand guarantees can significantly enhance the net value of a project with minimal cost to the government (Brandão et al., 2012). Similarly, Ashuri et al. (2012) employed a risk-neutral pricing method to assess the minimum revenue guarantee in Build-Operate-Transfer highway projects. Then, Zapata Quimbayo et al. (2018) expanded upon the evaluation method for minimum revenue guarantees by incorporating a mean-reverting process. On the other hand, Wang and Liu (2015) estimated the excess revenue of PPP projects under the government's minimum revenue guarantee. They argued that the government should share the excess revenue and proposed an optimal ratio for this revenue sharing. In a similar way, Li and Cai (2017) contended that governments should accurately assess government guarantees and charge the project company a corresponding guarantee fee. Furthermore, Wang et al. (2018a) suggested that the government should share project value increased by the minimum revenue guarantee and derive an optimal sharing ratio that would satisfy both parties. However, while their research primarily focuses on general government guarantee policies, this study delves deeper into tax reductions, which can be considered a form of guarantee, and risk-sharing policies, as these methods are popular for attracting the private sector. Regarding these two aspects, Yang et al. (2023) conducted an empirical analysis of the tax burden during the operation of PPP projects. They found that the impact of the "three exemptions and three halves", on the corporate income tax burden of the project needed careful consideration. On the other hand, Wang et al. (2018b) introduces the reciprocal preference theory to analyse the risk-sharing ratio and generates optimal incentive mechanisms. Despite a similar focus on tax and risk, this study not only evaluates the efficacy of these two support policies but explores their relative efficacy under different scenarios, aiming to effectively encourage private sector investment in PPPs.

2.2. Influence of government support policy on the investment behaviour of the private sector in PPP projects

The investment behaviours of private sector vary in response to different government support policies (Demirel et al., 2022; Fleta-Asín & Muñoz, 2023; Murwantara, 2023; Pellegrino, 2021; Stern, 1999; Wang et al., 2024). For example, Feng et al. (2015) found that the toll rate, the road quality and the road capacity of a BOT road project will be significantly different under the minimum traffic guarantee, the minimum revenue guarantee and the price compensation guarantee. Li and Cai (2017) have investigated how various government support policies, like revenue guarantees, concession period extensions, lump-sum subsidies, and unit subsidies, affect the investment behaviour of private sector. Their findings reveal that revenue guarantees, and concession period extensions do not impact private sector's decisions regarding capacity and pricing. In contrast, a lump-sum subsidy can lead to reduced capacity and higher prices, whereas a unit subsidy encourages increased capacity and lower prices. Moreover, despite not focusing on PPP projects, many scholars have concentrated on the influence of tax policies, like tax reductions and tax incentives, on investment (Chodorow-Reich et al., 2024; Daiyabu et al., 2023; Eichfelder et al., 2023; Liu & Mao, 2019; Su et al., 2023; Zwick & Mahon, 2017). They agree that tax policies could attract investment, despite sometimes being controversial. Building on these studies, this study examines how tax reductions impact investment behaviour, specifically within PPP mechanism. Risk-sharing is also a key factor influencing investment choice (Feng, 2023; Gatti, 2023; Su et al., 2021; Wu & Zhao, 2020). In PPP projects, the emphasis is on both the public and private parties sharing a large proportion of the risk (El-Kholy & Akal, 2021; Tallaki & Bracci, 2021; Zhang et al., 2021). Often, the public sector assumes minimal risk, aiming to transfer as much risk as possible to the private sector (Fu et al., 2023; Shi et al., 2023; Tallaki & Bracci, 2021). However, for urgent projects, governments are often willing to pay higher prices and assume a larger share of the risk to attract investment (Wang et al., 2018b). For instance, Carbonara et al. (2014) present a methodology for calculating the optimal concession period, aiming for a "win-win" outcome that ensures equitable risk sharing between the concessionaire and government. This study not only explores the impact of risk-sharing policy on investment decisions but also compares their efficacy with the tax reduction policy. Such analysis contributes to enriching the existing body of knowledge regarding policy incentives in PPP projects.

2.3. The relative efficacy of government support policy in promoting private investment in PPP project

To further evaluate the government support policies and investigate their influence on private investment, their relative efficacy in promoting and accelerating private investment has been investigated previously (Chilunjika, 2023; Mousa et al., 2023). Originating from the healthcare field, "relative efficacy" can be adapted to evaluate government support policies by assessing the extent to which one policy achieves more favourable outcomes than alternatives under ideal circumstances (Rathnayaka et al., 2024; Reynolds et al., 2020). Danielova and Sarkar (2011) considered the possibility of debt financing for private firms and suggested that government should combine the tax cut strategy with the investment subsidy strategy. Similar results were derived by Sarkar (2012), who compared tax cut and investment subsidy incentive strategy when the government uses a different discount rate from the private firm. However, Barbosa et al. (2016) found subsidies to be more beneficial than tax reductions for the host government, considering factors like entry costs and macroeconomic conditions. Moreover, Di Corato (2016) analysed the effect of government present-biased time preferences on the option of speeding up investment, and the result showed that tax reduction policy is optimal for the short-sighted government. Soumaré (2016) compared two forms of government support, i.e., loan guarantee and direct investment through PPPs, under the perfect and asymmetric information situations respectively. They argued that loan guarantee is more effective for the government. Tian (2018) focused on the optimal policy between the investment subsidy and tax rate reduction for attracting foreign direct investment and found that when the growth rate and the volatility of the project are high and the discount rate is low, tax rate reduction policy is preferable, otherwise, the investment subsidy is preferable. Despite the valuable insights provided by these previous studies, a consistent conclusion regarding the superior government incentive policy remains elusive. This gap underscores the need for further investigation. In response to these varied findings, this study specifically aims to compare the relative efficacy of the tax reduction and risk-sharing policies on private sector investment decisions in PPPs, seeking to identify the more effective policy under different scenarios.

3. Methodology

This research examined the effects of two governmental support policies, tax reduction and risk sharing, on the investment decision of the private sector based on a real-option pricing framework. In this framework, the project value is evaluated according to the prediction of the cash flow of the project, X, which is assumed to follow a Wiener process, $dX = \mu X dt + \sigma X dZ$. This is a standard assumption in the real-option pricing model and has been widely applied in PPP related studies (Silaghi & Sarkar, 2021;

Soumaré, 2016; Zapata Quimbayo & Mejía Vega, 2023). In the formula, μ means the expected rate of return of the project, σ means the volatility of the cash flow, and Z represents a standard Wiener process.

The private sector makes their investment entry decision, investment capital structure decision and investment withdraw decision sequentially based on the evaluation of the project. The investment decision process of the private sector is shown in Figure 1. First, the private sector needs to decide whether to invest in the project. Since the PPP project involves large investment amount but has an uncertain cash flow, the private sector will not invest in the project until the estimated project value is larger than its conserved value (*CV*). When this condition is satisfied, then, the private sector needs to further consider how to make its investment, namely, how to arrange its investment capital structure. The benefits of using debt capital are that it is tax deductible, but the weakness is that the likelihood of the project running into default is increased. Especially, when the cash flow of the project declines, the income of the project may not be affordable to the debt payment, the private sector needs to decide whether to withdraw from the project. If the private sector withdraws from the project, it will lose the opportunity that the cash flow of the project is improved; on the contrary, if the private sector persists in the project, it needs to shoulder the project's profit loss. Basically, there exists a default boundary value (*DBV*), when the project value is less than *DBV*, the private sector will default and withdraw from the project.

The governmental support policy will affect the evaluation of the project, thus influence the investment decision of the private sector. On one hand, the governmental support policy will increase the estimated project value, which increases the probability of the estimated project value before investment being larger than the private sector's *CV*, so attracting the private sector makes investment earlier. On the other hand, different governmental support policies will have a different influence on the optimal capital structure of the private sector, and further change the probability of the estimated project value after investment being lower than the private sector's *DBV*. The mechanism how different governmental support policies affect investment decision of the private sector is analysed in the following section, and their relative efficacy under different scenarios is compared.

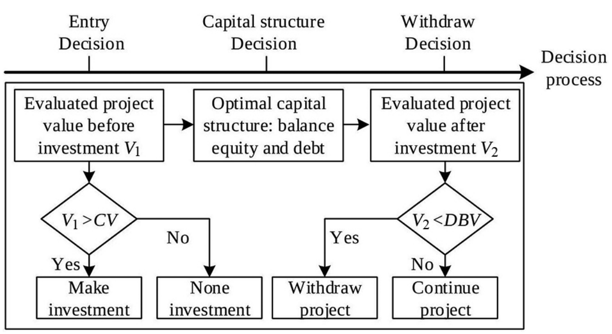

Figure 1. The decision process of the private sector in the PPP project under the real-option pricing framework

4. The investment decision analysis of private sector without governmental incentives

As a benchmark, this section will investigate the investment decision of the private sector when the government doesn't provide any incentive strategies. Suppose the debt used in the project is a perpetual zero coupon bond with coupon C, a similar way can be found in the studies of Soumaré (2016), Yuan et al. (2023), and Zapata Quimbayo and Mejía Vega (2023). The benefit of using debt capital is that it is tax deductible, but the weakness is that it may increase the default likelihood of the project (Wang et al., 2018a; Yuan et al., 2023). The default boundary value that keeps the private sector operating the project is denoted as X_D, when the cash flow value of the project is below this boundary value, the private sector will default, and the project will be turned over to the debt holder. However, since there are frictions during the transfer process, a fraction of the project value will be lost, suppose this loss equals to αX_D, $0<\alpha<1$. After the private sector defaults, the residual value of project equals to $E\left[\left(\left(1-\alpha\right)X_D\right)\right]=\frac{1-\alpha}{r}X_D$.

4.1. In the operation period

During the operation period, the project value is denoted as $\bar{V}_O\left(X\right)$, the debt value is $\bar{D}_O\left(X\right)$, and the equity value is $\bar{E}_O\left(X\right)$. Following the study of Dixit and Pindyck (1994), the equity value $\bar{E}_O\left(X\right)$ satisfies the following Bellman equation:

$$r\bar{E}_O\left(X\right)dt=\left(1-\tau\right)\left(X-C\right)dt+E\left(d\bar{E}_O\left(X\right)\right). \tag{1}$$

According to Ito's lemma (Dixit & Pindyck, 1994), Eqn (1) can be translated into the following DE:

$$\frac{1}{2\sigma^2X^2\dfrac{\partial^2\bar{E}_O\left(X\right)}{\partial X^2}}+\mu X\frac{\partial\bar{E}_O\left(X\right)}{\partial X}-r\bar{E}_O\left(X\right)+\left(1-\tau\right)\left(X-C\right)=0. \tag{2}$$

The expression of the equity value can be derived by solving the DE, as follows:

$$\bar{E}_O\left(X\right)=\frac{1-\tau}{r-\mu}X-\frac{1-\tau}{r}C+C_1X^{\beta_1}+C_2X^{\beta_2}. \tag{3}$$

In this equation, β_1 and β_2 are the positive and negative solutions of equation $\frac{1}{2}\sigma^2x\left(x-1\right)+\mu x-r=0$, respectively. $\beta_2=\frac{1}{2}-\frac{\mu}{\sigma^2}-\sqrt{\left(\frac{1}{2}-\frac{\mu}{\sigma^2}\right)^2+\frac{2r}{\sigma^2}}<0$. C_1 and C_2 are the constants to be solved. Based on non-bubble condition (Dixit & Pindyck, 1994), C_1 must equal 0. Similarly, $\bar{E}_O\left(X\right)$ should satisfy the value matching condition (4) and smooth passing condition (5):

$$\bar{E}_O\left(X_D\right)=0; \tag{4}$$

$$\frac{\partial \bar{E}_O(X)}{\partial X}|_{X=X_D}=0. \tag{5}$$

Combining the Eqns (3), (4), and (5), the analytic solution of $\bar{E}_O(X)$ and X_D can be derived:

$$\bar{E}_O(X)=\frac{1-\tau}{r-\mu}X-\frac{1-\tau}{r}C-\left(\frac{1-\tau}{r-\mu}X_D-\frac{1-\tau}{r}C\right)\left(\frac{X}{X_D}\right)^{\beta_2}; \tag{6}$$

$$X_D=\frac{r-\mu}{r}\frac{\beta_2}{\beta_2-1}C. \tag{7}$$

The value of the project $\bar{V}_O(X)$ satisfies the following Bellman equation:

$$r\bar{V}_O(X)dt=\left[(1-\tau)X+\tau C\right]dt+E\left(d\bar{V}_O(X)\right). \tag{8}$$

In a similar way, this equation can be translated into the following DE:

$$1/2\sigma^2X^2\frac{\partial^2\bar{V}_O(X)}{\partial X^2}+\mu X\frac{\partial \bar{V}_O(X)}{\partial X}-r\bar{V}_O(X)+(1-\tau)X+\tau C=0, \tag{9}$$

by solving this DE, $\bar{V}_O(X)$ can be expressed as:

$$\bar{V}_O(X)=\frac{1-\tau}{r-\mu}X+\frac{\tau C}{r}+D_1X^{\beta_1}+D_2X^{\beta_2}, \tag{10}$$

where D_1 and D_2 are the constants to be solved. Besides, two boundary conditions need to be satisfied, as follows:

$$\lim_{X\to\infty}\frac{V_O(X)}{X}<\infty; \tag{11}$$

$$\bar{V}_O(\bar{X}_D)=\frac{1-\alpha}{r}X_D. \tag{12}$$

The boundary condition (11) is the non-bubble condition, and the boundary condition (12) is the value matching condition. Combining Eqns (10), (11) and (12), the expression of $\bar{V}_O(X)$ can be derived:

$$\bar{V}_O(X)=\frac{1-\tau}{r-\mu}X+\frac{\tau C}{r}+\left[\left(\frac{1-\alpha}{r}-\frac{1-\tau}{r-\mu}\right)X_D-\frac{\tau}{r}C\right]\left(\frac{X}{X_D}\right)^{\beta_2}. \tag{13}$$

Therefore, the expression of $\bar{D}_O(X)$, is

$$\bar{D}_O(X)=\bar{V}_O(X)-\bar{E}_O(X)=\frac{C}{r}+\left(\frac{1-\alpha}{r}X_D-\frac{C}{r}\right)\left(\frac{X}{X_D}\right)^{\beta_2}. \tag{14}$$

The private sector decides the optimal debt level to maximize the project value:

$$\max_C\left(\bar{V}_O(X)\right). \tag{15}$$

By solving this maximum problem, the optimal debt level of the project can be expressed as

$$C^*=\frac{r}{r-\mu}\frac{\beta_2-1}{\beta_2}AX, \tag{16}$$

where * means the optimal level, and

$$A=\left(\frac{\tau-\beta_2+\frac{(r-\mu)(1-\alpha)\beta_2}{r}}{\tau}\right)^{\frac{1}{\beta_2}}.$$

Denote $P=\frac{r}{r-\mu}\frac{\beta_2-1}{\beta_2}A$, the optimal debt level $C^*=PX$. Then, the default boundary value X_D equals:

$$X_D=AX. \tag{17}$$

The value of the project in the operation period can be expressed as:

$$\bar{V}_O(X)=BX, \tag{18}$$

where $B=\frac{1}{r-\mu}(1-\tau+\tau A)$.

4.2. Before the investment

Since the infrastructure investment involves a large amount of capitals, and the investment is irreversible, the private sector needs to verify the feasibility of the project carefully before making investment. Therefore, there exits an investment boundary, denoted as $\bar{X}_I$, only when the cash flow of the project is higher than this boundary, will the private sector invest in the project. Since the private sector in the PPP project mainly relies on operating the project to recoup the investment, the completion risk of the project should be a critical concern for the private sector (Geng et al., 2023a). Besides, there exists competition in the infrastructure market, whether it is possible to get the investment opportunity may also influence the investment decision of the private sector (Wang et al., 2019). Denote the probability that the private sector can get the investment opportunity and the completion risk occurs as ρ and η respectively. Suppose the value of the project is $\bar{V}(X)$ and debt value is $\bar{D}(X)\cdot\bar{V}(X)$ satisfies the following Bellman equation:

$$r\bar{V}(X)dt=E\left(d\bar{V}(X)\right). \tag{19}$$

According to Ito's lemma, this equation can be translated into the following equation:

$$r\bar{V}(X)=\frac{1}{2}\sigma^2X^2\frac{\partial^2\bar{V}(X)}{\partial X^2}+\mu X\frac{\partial\bar{V}(X)}{\partial X}+ (1-\rho)\left(0-\bar{V}(X)\right)+\rho\left((1-\eta)\bar{V}_O(X)-I\right). \tag{20}$$

The solution of this equation can be expressed as:

$$\bar{V}(X)=\frac{\rho(1-\eta)B}{1+r-\rho-\mu}X-\frac{\rho I}{1+r-\rho}+F_1X^{\gamma_1}+F_2X^{\gamma_2}, \tag{21}$$

where γ_1 and γ_2 are the positive and negative solutions of the equation $\frac{1}{2}\sigma^2x(x-1)+\mu x-(1+r-\rho)=0$, respectively. $\gamma_1=\sqrt{\left(\frac{1}{2}-\frac{\mu}{\sigma^2}\right)^2+\frac{2(1+r-\rho)}{\sigma^2}}+\frac{1}{2}-\frac{\mu}{\sigma^2}>0.$ F_1 and F_2 are the constants to be solved. Since when X equals 0, $\bar{V}(X)$ also equals 0, this implies that F_2 = 0. Moreover, $\bar{V}(X)$ must satisfy the value matching condition (22) and smooth passing condition (23) at the investment boundary $\bar{X}_I$. Namely:

$$\bar{V}(\bar{X}_I)=(1-\eta)\bar{V}_O(\bar{X}_I)-I; \tag{22}$$

$$\left.\frac{\partial \bar{V}(X)}{\partial X}\right|_{X=\bar{X}_I} = (1-\eta)\left.\frac{\partial \bar{V}_O(X)}{\partial X}\right|_{X=\bar{X}_I}. \quad (23)$$

Combining Eqns (21), (22), and (23), the analytic expression of the project value and the investment boundary can be derived respectively:

$$\bar{V}(X) = \left(\frac{1+r-2\rho-\mu}{1+r-\rho-\mu}(1-\eta)B\bar{X}_I - \frac{1+r-2\rho}{1+r-\rho}I\right)\left(\frac{X}{\bar{X}_I}\right)^{\gamma_1} + \frac{\rho(1-\eta)B}{1+r-\rho-\mu}X - \frac{\rho I}{1+r-\rho}; \quad (24)$$

$$\bar{X}_I = \frac{\gamma_1}{\gamma_1-1}\frac{1+r-\rho-\mu}{1+r-2\rho-\mu}\frac{1}{(1-\eta)B}\frac{1+r-2\rho}{1+r-\rho}I. \quad (25)$$

Proposition 1: *The investment boundary of private sector $(\bar{X}_I)$ increases with the probability of getting the investment opportunity* (ρ) *and the completion risk* (η).

Proposition 1 manifests that the easier the private sector can get the investment opportunity, and the larger is the completion risk, the later the private sector invests in the project. This result indicates that the government can take two kinds of measures to motivate the private sector to invest in the infrastructure project, one kind of measures is increasing the competition of the infrastructure market, e.g., reducing tax rate, and offering direct governmental subsidies for infrastructure development. In these ways, more private sectors may participate into infrastructure development, so the competition of the infrastructure market is increased. The other kind of measures are sharing the completion risk with the private sector, which can not only directly decrease the investment boundary of the private sector, but also increase the competition of the infrastructure market, which further decrease the investment boundary of the private sector. However, sharing the completion risk with the private sector will increase the potential liabilities of the government. Therefore, the government should trade off the advantages and disadvantages between the two kinds of measures when making the incentive policy. Please see the Appendix for the proof of this proposition.

4.3. The benefits of the government

The benefits of the government come from tax revenue generated by project. In the operating period, denote the benefits of the government as $G(X)$, then the following equation is satisfied.

$$1/2\sigma^2 G_{XX}(X) + \mu X G_X(X) - rG(X) + \tau(X-C) = 0, \quad (26)$$

where $G(X)$ needs to satisfy two other conditions:

$$\lim_{X\to\infty}\frac{G(X)}{X} < \infty; \quad (27)$$

$$G(X=C) = 0. \quad (28)$$

The condition (27) manifests the non-bubble condition, and the condition (28) reflects that when the cash flow of the project is below the debt payment requirement, the government cannot obtain tax benefits anymore. Combining these conditions, the analytic expression of the benefits of the government $G(X)$ can be derived:

$$G(X) = \frac{\tau}{r-\mu}X - \frac{\tau}{r}C - \frac{\mu}{r(r-\mu)}\tau C\left(\frac{X}{C}\right)^{\beta_2}. \quad (29)$$

Under the optimal debt level $C^* = PX$, the benefits of the government will satisfy $G(X) = \left(\frac{\tau}{r-\mu} - \frac{\tau}{r}P - \frac{\tau\mu}{r(r-\mu)}P^{1-\beta_2}\right)X$.

If denote $Q = \left(\frac{\tau}{r-\mu} - \frac{\tau}{r}P - \frac{\tau\mu}{r(r-\mu)}P^{1-\beta_2}\right)$, then $G(X) = QX$. Suppose the total benefits of the project is $W(X)$, then $W(X) = \bar{V}(X) + G(X)$.

Proposition 2: *There exists an optimal tax rate τ^* that makes the benefits of the government maximum.*

Proposition 2 manifests that if the government can adjust the tax rate of the infrastructure, it is not always beneficial to the government to set a high tax rate (e.g., $\tau > \tau^*$). Because if the government sets a high tax rate, the private sector will use more debt capital to get more tax shield benefits (since $\frac{\partial C^*}{\partial \tau} > 0$), which in turn tightens the constrain condition (27). Therefore, when determining tax rate, the government should trade off the direct benefits from increasing the tax rate and the potential loss caused by the private sector's capital structure adjustment. Please see the Appendix for the proof of this proposition.

5. The investment decision analysis of the private sector under tax reduction incentive strategy of the government

To motivate the private sector to participate in the infrastructure investment, the government may promise to give back some tax benefits of the project to the private sector. This section will investigate how the tax reduction incentive strategy of the government affects investment decision of the private sector.

5.1. In the operation period

Suppose the government promises to transfer δ percentage of the tax benefits to the private sector. Then, the equity value of the private sector $\bar{E}_O^1(X)$ satisfies:

$$1/2\sigma^2 X^2 \frac{\partial^2 \bar{E}_O^1(X)}{\partial X^2} + \mu X \frac{\partial \bar{E}_O^1(X)}{\partial X} - r\bar{E}_O^1(X) + (1-\tau)(X-C) + \delta Q X = 0. \quad (30)$$

Suppose the default boundary of the private sector is X_D^1, combining the boundary conditions (4) and (5), the analytic expression of the default boundary X_D^1 can be derived:

$$X_D^1 = \frac{r-\mu}{r}\frac{1-\tau}{1-\tau+\delta Q}\frac{\beta_2}{\beta_2-1}C. \quad (31)$$

Compared with the benchmark scenario, a proposition is proposed as follows:

Proposition 3: *The tax reduction incentive strategy can effectively decrease the default boundary of the private sector* $\left(X_D^1 < X_D\right)$.

Proposition 3 manifests that the government can keep the private sector involving in the project longer at the sacrifice of tax revenue. This result suggests that: if a strategic PPP project runs into distress for the time being, and it cannot be terminated for its strategic purpose, government can keep the private sector from exiting the project by reducing the tax rate. Please see the Appendix for the proof of this proposition.

Under the tax reduction incentive strategy of the government, the project value in the operation period $\bar{V}_O^1(X)$ satisfies:

$$\bar{V}_O^1(X) = \frac{1-\tau+\delta Q}{r-\mu}X + \frac{\tau}{r}C + \left(\left(\frac{1-\alpha}{r} - \frac{1-\tau+\delta Q}{r-\mu}\right)\bar{X}_D^1 - \frac{\tau}{r}C\right)\left(\frac{X}{\bar{X}_D^1}\right)^{\beta_2}. \tag{32}$$

The private sector will choose an optimal debt level C_1^* to maximize the project value $\bar{V}_O^1(X)$, that is:

$$\max_{C_1^*} V_O^1(X). \tag{33}$$

Solving this maximization problem can derive the analytic expression of the optimal debt level C_1^*:

$$C_1^* = \frac{r}{r-\mu}\frac{1-\tau+\delta Q}{1-\tau}\frac{\beta_2-1}{\beta_2}A_1X, \tag{34}$$

where

$$A_1 = \left(\frac{(\tau-\beta_2)(1-\tau+\delta Q) + \frac{(r-\mu)(1-\alpha)(1-\tau)\beta_2}{r}}{\tau(1-\tau+\delta Q)}\right)^{\frac{1}{\beta_2}}.$$

Moreover, the optimal debt level can set as $C_1^* = P_1X$, where $P_1 = \frac{r}{r-\mu}\frac{1-\tau+\delta Q}{1-\tau}\frac{\beta_2-1}{\beta_2}A_1$. By analyzing the expression of the optimal debt level, a proposition is proposed as follows:

Proposition 4: *When the tax reduction ratio* $\delta \le \frac{(1-\tau)}{Q}\left(\frac{(r-\mu)(1-\alpha)(1-\beta_2)}{r(\tau-\beta_2)} - 1\right)$, *the optimal debt level of the private sector decreases with the tax reduction ratio* δ; *otherwise, the optimal debt level of the private sector increases with the tax reduction ratio* δ.

Proposition 4 manifests that there exists a U-shape relationship between the optimal debt level and the incentive ratio. Under the tax reduction incentive strategy of the government, the benefits of the private sector come from two aspects: the after-tax earnings of the project and the tax reduction benefits from the government. Increasing the debt level of the project will increase the after-tax earnings of the project on one hand but decrease the tax reduction benefits from the government on the other hand. Therefore, the private sector needs to balance the benefits from both sides when determining the optimal debt level of the project. When the tax reduction ratio is relatively small, it beneficial for the private sector to decrease the debt level. The reason is that reducing the debt level can increase the tax benefits transferred from the government which is risk-free. That is to say, the private sector transfers the risky tax shield benefits (since debt capital may cause the default risk) to the risk-free tax benefits by reducing the debt level. However, when the tax reduction ratio is relatively large, it is beneficial for the private sector to increase the debt level to increase the after-tax earnings of the project. Please see the Appendix for the proof of this proposition.

Under the optimal debt level, the project value in the operation period and the default boundary of the private sector can be respectively expressed as:

$$\bar{V}_O^1(X) = B_1X; \tag{35}$$

$$X_D^1 = A_1X, \tag{36}$$

where $B_1 = \frac{1-\tau+\delta Q}{r-\mu}\left(1+\frac{\tau}{1-\tau}A_1\right)$.

5.2. Before the investment

The tax reduction incentive strategy of the government will increase the competition of the infrastructure market, which decreases the probability that a private sector can get the investment opportunity (Yuan et al., 2023). In this scenario, suppose the probability that a private sector gets investment is $\rho - a\delta, 0 < a < \frac{\rho}{\delta}$, where a reflects the sensitivity of the infrastructure market to the tax reduction incentive strategy. The project value before the investment $\bar{V}_1(X)$ satisfies:

$$r\bar{V}_1(X) = \frac{1}{2}\sigma^2X^2\frac{\partial^2\bar{V}_1(X)}{\partial X^2} + \mu X\frac{\partial\bar{V}_1(X)}{\partial X} + (1-\rho+a\delta)\left(0-\bar{V}_1(X)\right) + (\rho-a\delta)\left((1-\eta)\bar{V}_O^1(X) - I\right). \tag{37}$$

Solving this equation like the above process can derive the analytic expression of the project value before the investment:

$$\bar{V}_1(X) = \left(\frac{1+r+2a\delta-2\rho-\mu}{1+r+a\delta-\rho-\mu}(1-\eta)B_1\bar{X}_I^1 - \frac{1+r+2a\delta-2\rho}{1+r+a\delta-\rho}I\right)\left(\frac{X}{\bar{X}_I^1}\right)^{\xi_1} + \frac{(\rho-a\delta)(1-\eta)B_1}{1+r+a\delta-\rho-\mu}X - \frac{(\rho-a\delta)I}{1+r+a\delta-\rho}. \tag{38}$$

The analytic expression of the investment boundary can also be derived:

$$\bar{X}_I^1 = \frac{\xi_1}{\xi_1-1}\frac{1+r+a\delta-\rho-\mu}{1+r+2a\delta-2\rho-\mu}\frac{1}{(1-\eta)B_1}\frac{1+r+2a\delta-2\rho}{1+r+a\delta-\rho}I, \tag{39}$$

where ξ_1 is the positive root of the equation $\frac{\sigma^2}{2}\xi(\xi-1) + \mu\xi - (1+a\delta+r-\rho) = 0$, so

$$\xi_1 = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2(1 + a\delta + r - \rho)}{\sigma^2}}.$$

By analyzing the expression of the investment boundary, a proposition is proposed as follows:

Proposition 5: *The investment boundary $\bar{X}_I^1$ decreases with the tax reduction ratio δ and the sensitivity of the infrastructure market to the incentive strategy (a).*

Proposition 5 indicates that the government can use the tax reduction incentive strategy to motivate the private sector to invest in project, and the effectiveness of the incentive strategy relies on the sensitivity of the infrastructure market: the more sensitive the infrastructure market to the tax reduction incentive, the more effective will be the tax reduction incentive strategy. Please see the Appendix for the proof of this proposition.

5.3. The benefits of the government

The tax benefits of the government $G^1(X)$ satisfy:

$$1/2\sigma^2 G^1_{XX}(X) + \mu X G^1_X(X) - rG^1(X) + \tau\left(X - C_1^*\right) - \delta QX = 0. \tag{40}$$

Based on the conditions (26) and (27), the analytic expression of $G^1(X)$ can be derived:

$$G^1(X) = Q_1 X, \tag{41}$$

where $Q_1 = \left(\frac{\tau}{r-\mu} - \frac{\tau}{r}P_1 - \frac{\tau\mu}{r(r-\mu)}P_1^{1-\beta_2} - \frac{\delta Q}{r-\mu}\left(1 - P_1^{1-\beta_2}\right)\right)$.

Therefore, the total benefits of project, denoted as $W^1(X)$, satisfies $W^1(X) = \bar{V}^1(X) + G^1(X)$.

6. The investment decision analysis of the private sector under risk sharing incentive strategy of the government

Since the construction of some infrastructures is highly complexity, and the private sector mainly relies on operating the infrastructure to recover investment, whether the project can be completed on time is a key factor that influences the private sector's participation decision to the project (Geng et al., 2023b; Wang et al., 2018b). In this section, sharing the completion risk with the private sector is considered as an incentive strategy of the government to promote the private sector to invest in the infrastructure. Furthermore, how this incentive strategy influences the investment decision of the private sector is investigated.

6.1. Before the investment

Suppose the government shares the completion risk with the private sector by means of paying back a share of construction cost $(\delta_0 I, 0 < \delta_0 < 1)$ to the private sector once the completion risk happens. In this scenario, the private sector's investment behaviour in operation period is not affected, while the competition of the infrastructure market is increased. Suppose the probability that a private sector can get the investment is $\rho - a_0\delta_0$, $a_0\left(0 < a_0 < \frac{\rho}{\delta_0}\right)$ means the sensitivity of the infrastructure market to the risk sharing incentive strategy. the project value before the investment $\bar{V}^2(X)$ satisfies:

$$r\bar{V}^2(X) = \frac{1}{2}\sigma^2 X^2 \frac{\partial^2 \bar{V}^2(X)}{\partial X^2} + \mu X \frac{\partial \bar{V}^2(X)}{\partial X} + (1 + a_0\delta_0 - \rho)\left(0 - \bar{V}^2(X)\right) + (\rho - a_0\delta_0)\left((1-\eta)\bar{V}_O(X) - (1 - \delta_0\eta)I\right). \tag{42}$$

Combining the boundary conditions (21) and (22), the analytic expression of the project value and the investment boundary can be derived:

$$\bar{V}^2(X) = \frac{(\rho - a_0\delta_0)(1-\eta)B}{1 + r + a_0\delta_0 - \rho - \mu}X - \frac{(\rho - a_0\delta_0)(1 - \delta_0\eta)I}{1 + r + a_0\delta_0 - \rho} + \left(\frac{1 + r + 2a_0\delta_0 - 2\rho - \mu}{1 + r + a_0\delta_0 - \rho - \mu}(1-\eta)B\bar{X}_I^2\right)\left(\frac{X}{\bar{X}_I^2}\right)^{\zeta_1} - \frac{(1 + r + 2a_0\delta_0 - 2\rho)(1 - \delta_0\eta)}{1 + r + a_0\delta_0 - \rho}I\left(\frac{X}{\bar{X}_I^2}\right)^{\zeta_1}; \tag{43}$$

$$\bar{X}_I^2 = \frac{\zeta_1}{\zeta_1 - 1}\frac{1 + r + a_0\delta_0 - \rho - \mu}{1 + r + 2a_0\delta_0 - 2\rho - \mu}\frac{(1 - \delta_0\eta)}{(1-\eta)B}\frac{1 + r + 2a_0\delta_0 - 2\rho}{1 + r + a_0\delta_0 - \rho}I, \tag{44}$$

where ζ_1 is the positive solution of the equation $\frac{1}{2}\sigma^2\zeta(\zeta - 1) + \mu\zeta - (1 + a_0\delta_0 + r - \rho) = 0$, so

$$\zeta_1 = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu}{\sigma^2}\right)^2 + \frac{2(1 + a_0\delta_0 + r - \rho)}{\sigma^2}}.$$

By analyzing the expression of investment boundary, a proposition is proposed as follows:

Proposition 6: *The investment boundary $\bar{X}_I^2$ decreases with the risk sharing ratio δ_0 and the sensitivity of the infrastructure market to the incentive strategy (a_0).*

Proposition 6 reflects that risk sharing incentive strategy is an alternative incentive strategy which can effectively promote the private sector to invest in the project. By comparing the investment boundary under two incentive strategies, the following proposition is proposed. Please see the Appendix for the proof of this proposition.

Proposition 7: *When $a = a_0$, and $\delta = \delta_0$, if the completion risk satisfies $\eta < \frac{1}{\delta}\frac{B_1 - B}{B_1}$, the investment boundary of the private sector under the risk sharing incentive strategy is higher than that under the tax reduction incentive strategy, $\bar{X}_I^2 > \bar{X}_I^1$. Otherwise, if the completion risk satisfies $\eta \geq \frac{1}{\delta}\frac{B_1 - B}{B_1}$, the investment boundary of the private sector under the risk sharing incentive strategy is lower than that under the tax reduction incentive strategy, $\bar{X}_I^2 \leq \bar{X}_I^1$.*

Proposition 7 manifests that the relative efficacy of the two incentive strategies under the same incentive ratio depends on the magnitude of completion risk. If the completion risk is relatively small, the tax reduction incentive strategy is more effective to motivate the private sector than the risk sharing incentive strategy; on the contrary, if the completion risk is large, the risk sharing incentive strategy is more effective to motivate the private sector than the tax reduction incentive strategy. Please see the Appendix for the proof of this proposition.

6.2. The benefits of the government

Under the risk sharing incentive strategy, the tax benefits of the government $G^2(X)$ satisfies:

$$1/2\sigma^2 G_{XX}^2(X) + \mu X G_X^2(X) - rG^2(X) + \tau(X - C^*) - \delta_0 \eta I = 0. \quad (45)$$

It can be derived that the analytic expression of $G^2(X)$ satisfies $G^2(X) = QX - \frac{\eta\delta_0 I}{r}$. The total benefits of project $W^2(X)$ satisfies $W^2(X) = \bar{V}^2(X) + G^2(X)$. By comparing the expression of the tax benefits of the government under the tax reduction incentive strategy and the risk sharing incentive strategy, a proposition is proposed as follows:

Proposition 8: *When $a = a_0$, $\delta = \delta_0$ and $\eta = \frac{1}{\delta}\frac{B_1 - B}{B_1}$, the investment boundary of the private sector is the same under two different incentive strategies. If $I < \frac{(Q - Q_1)B_1 rX}{B_1 - B}$, the benefits of the government under the risk sharing incentive strategy is larger than that under the tax reduction incentive strategy, $G^2(X) > G^1(X)$; otherwise, if $I \geq \frac{(Q - Q_1)B_1 rX}{B_1 - B}$, the benefits of the government under the risk sharing incentive strategy is lower than that under the tax reduction incentive strategy, $G^2(X) \leq G^1(X)$.*

Proposition 8 reflects that when the incentive effect is same under two incentive strategies, the relative incentive loss of the government depends on the magnitude of the construction cost. If the construction cost is relatively small, the incentive loss of the government under the risk sharing incentive strategy is smaller than that under the tax reduction incentive strategy; otherwise, if the construction cost is relatively large, the incentive loss of the government under the risk sharing incentive strategy is larger than that under the tax reduction incentive strategy. Please see the Appendix for the proof of this proposition.

If keep the incentive loss of the government as the same under two incentive strategies, a proposition about the relationship between the incentive ratios under two incentive strategies is proposed as follows:

Proposition 9: *Under the same incentive loss of the government, the incentive ratio under two incentive strategies satisfies $\delta_0 = \frac{rX(Q - Q_1)}{\eta I}$.*

Proposition 9 gives out the relationship between the incentive ratios under two incentive strategies if the government keeps the incentive cost as the same. Besides, it can be derived that the larger the completion risk probability (η) and the construction cost (I), the smaller the incentive ratio under the risk sharing incentive strategy (δ_0); while the larger the government loss caused by the tax reduction incentive strategy ($Q - Q_1$) and the risk-free interest rate, the larger the incentive ratio under risk sharing incentive strategy (δ_0). Under the same incentive loss of the government scenario, the relative efficacy of two incentive strategies may be different with that under the same incentive ratio scenario, which will be numerically investigated in the next section. Please see the Appendix for the proof of this proposition.

If keep the incentive effect as the same under two incentive strategies, i.e., the investment boundary of the private sector under two incentive strategies is $\bar{X}_I^1 = \bar{X}_I^2$. The relationship between the incentive ratios under two incentive strategies is numerically investigated in the next section.

7. The numerical analysis

This section offers several thoughtful insights by examining the property of the model solution. In particular, three scenarios are considered: the first scenario is that the incentive ratio under two incentive strategies is same; the second scenario is that the incentive loss of the government under two incentive strategies is same; and the third scenario is that the incentive effect under two incentive strategies is the same. We focus on the impact of different incentive strategies of the government on the investment decision of the private sector, including the capital structure decision and the investment boundary. How different incentive strategies affect total benefits of the project is also investigated. The base case parameters used in this analysis are set similar with the existing real-options PPP models (Silaghi & Sarkar, 2021; Yang et al., 2023; Zapata Quimbayo & Mejía Vega, 2023): $r = 0.08$ for the risk-free interest rate, $\mu = 0.02$ for the risk neutral expected rate of return of the project, $\sigma = 0.05$ for the volatility of the cash flow, $\tau = 0.15$ for the tax rate, $\alpha = 0.1$ for the degree of the default loss, $I = 2$ (million) for the construction cost, and $X = 0.1$ (million) for the initial cash flow value. These values are used to analyse the model solutions unless stated otherwise.

7.1. Under the same incentive ratio

7.1.1. The impact of incentive strategies of the government on capital structure decision of the private sector

Based on the model solution, the incentive strategy that sharing the construction risk with the private sector does not change the capital structure decision of the private sector, therefore, the optimal capital structure of the project under the risk sharing incentive strategy is the same with that under the benchmark scenario. Figure 1 depicts the impact of the tax reduction incentive strategy on the capital structure decision of the private sector. From the Figure 2, it can be found that the optimal debt level is influenced by the tax reduction ratio (δ) and the degree of the default loss (α). When the degree of the default loss is small (α = 0.01), the left figure manifests that the tax reduction incentive strategy promotes the private sector to reduce the debt level of the project $\left(C^* > C_1^*\right)$, and the larger is the tax reduction ratio, the more will the private sector reduce the debt level of the project. However, when the degree of the default loss is relatively large (α = 0.1), the right figure reflects that the tax reduction incentive strategy motivates the private sector to increase the debt level of the project $\left(C^* < C_1^*\right)$, and the larger is the tax reduction ratio, the more will the private sector increases the debt level of the project. Therefore, ***proposition 4*** is numerically verified. Based on the above results, it can be derived that if the project is easily redeployable after running into trouble, the private sector will use less debt capital under the tax reduction incentive than under the risk sharing incentive; however, if the project is hardly redeployable after running into trouble, the private sector will use more debt capital under the tax reduction incentive than under the risk sharing incentive.

As a matter of fact, reducing tax rate may not necessarily reduce tax benefits of the government. Figure 3 depicts the relationship between the tax benefits of the government and the tax rate. It is a reverse U-shape relationship between tax benefits of the government and the tax rate. Therefore, the ***proposition 2*** is numerically verified. It can be also found that the optimal tax rate is related to the volatility of the project, and the larger is the volatility of the project, the larger is the optimal taxrate$\left(\tau^*\left(\sigma = 0.2\right) > \tau^*\left(\sigma = 0.15\right) > \tau^*\left(\sigma = 0.1\right)\right)$.

7.1.2. The impact of incentive strategies of the government on investment boundary of the private sector

Figure 4 shows how the completion risk and investment opportunity influence the investment boundary of the private sector. both a large completion risk and a large investment opportunity will increase investment boundary of the private sector, which numerically verifies ***proposition 1***. Hence, the government can take measures to reduce the completion risk or increase the market competition to promote the private sector to invest in the project.

When the sensitivity of infrastructure market to the incentive strategy is the same ($a = a_0 = 2$), and the incentive ratio is the same ($\delta = \delta_0$), Figure 5 displays the relationship between the investment boundary of the private sector and the incentive ratio under different incentive strategies. It can be seen that both the incentive strategies can effectively motivate the private sector to invest in the project.

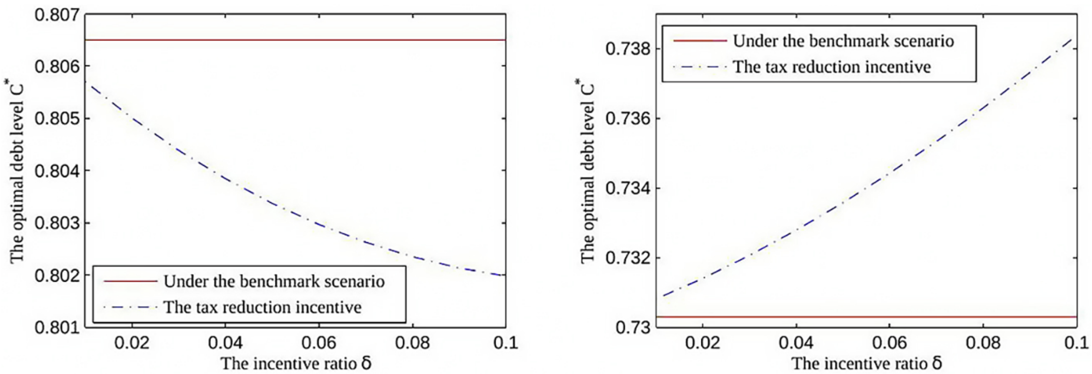

Figure 2. The impact of the incentive strategy on the capital structure decision of the private sector (α = 0.01 and α = 0.1, respectively)

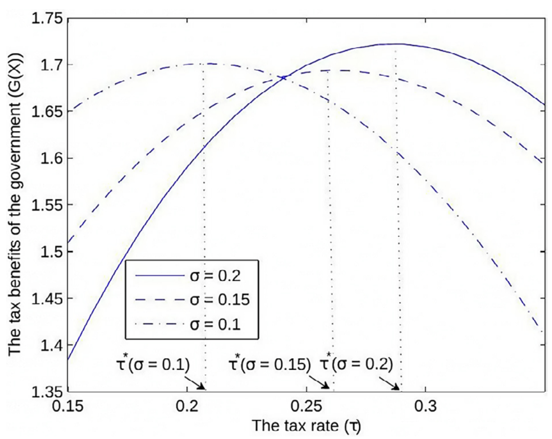

Figure 3. The relationship between the tax benefits of the government and the tax rate

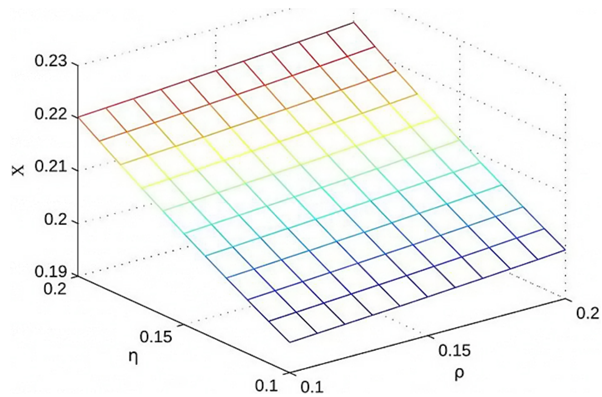

Figure 4. The impact of the completion risk and the investment opportunity on the investment boundary of the private sector

However, the relative efficacy of two incentive strategies is different under different scenarios. In details, when the completion risk of the project is large (η = 0.1), the risk sharing incentive strategy can motivate the private sector to invest earlier than tax reduction incentive strategy (the left figure); while when completion risk of the project is small (η = 0.001), the tax reduction incentive strategy can promote the private sector to invest earlier than risk sharing incentive strategy (the right figure). Therefore, the ***proposition 7*** is numerically verified. These results suggest that the government should make particular incentive policy for different projects to increase the effectiveness of the incentive strategy: the risk sharing incentive strategy should be used for the highly complicated project, while the tax reduction incentive strategy should be used for the less complicated project.

In particular, the effectiveness of different incentive strategies also relies on the sensitivity of the infrastructure market. Figure 6 depicts the relationship between the investment boundary and the incentive ratio under four different situations. The benchmark situation (the top left figure) is that the infrastructure market has the same sensitivity to both incentive strategies, $a = a_0 = 2$. Under this situation, the risk sharing incentive strategy can promote the private sector to invest earlier than the tax reduction incentive strategy. With the decrease of the sensitivity of the infrastructure market to the risk sharing incentive strategy, the incentive effect of the risk sharing incentive strategy is decreasing. When the the sensitivity of the infrastructure market to the risk sharing incentive strategy decreases to $a_0 = 0.5$, the incentive effect of the tax reduction incentive strategy become larger than the risk sharing

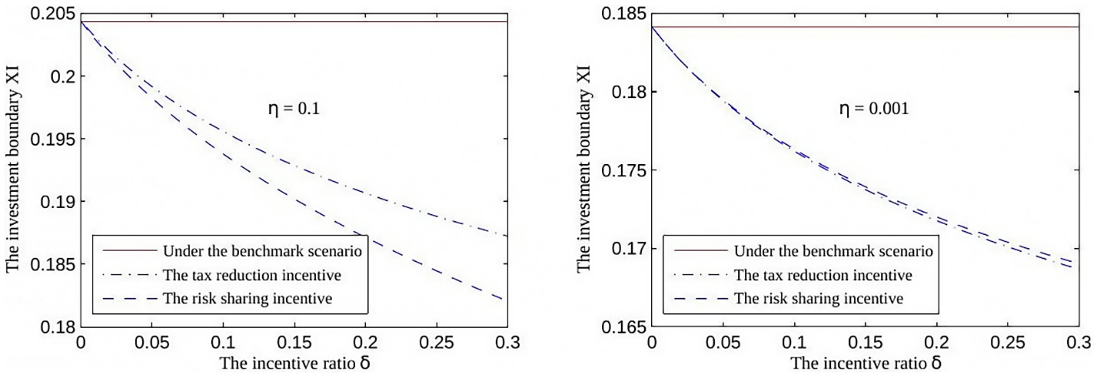

Figure 5. The impact of the incentive strategy on the investment boundary of the private sector (η = 0.1 and η = 0.001, respectively)

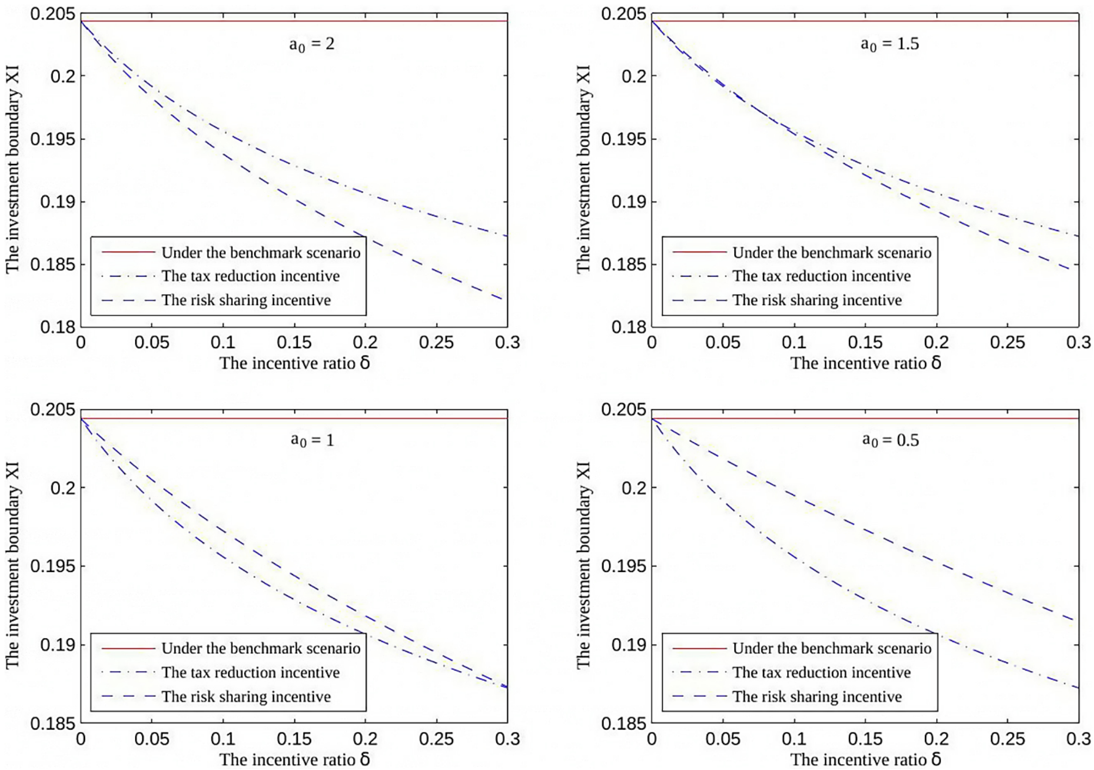

Figure 6. The impact of the sensitivity of the infrastructure market on the effectiveness of different incentive strategies (η = 0.1)

incentive strategy (the low right figure). Based on the above analysis, it can be derived that when the completion risk is relatively large and under the same incentive ratio, the risk sharing policy is relatively more effective than the tax reduction policy to promote the private sector to invest in PPP projects.

7.1.3. The impact of the incentive strategies on the total benefits of the project

Figure 7 shows the relationship between the total benefits of the project and the incentive ratio under different scenarios. It can be seen that the total benefit of the project is larger under the tax reduction incentive strategy than that under the risk sharing incentive strategy. Especially, when both the tax rate and completion risk are large (τ = 0.3 and η = 0.1), the risk sharing incentive strategy even decreases the total benefits of the project. That is to say, there exists efficiency loss under risk sharing incentive strategy, since the benefits loss of the government are larger than the benefits gain of the private sector $\left(G_1 - G_3 > V_3 - V_1\right)$. The intuition is that the government is not better to manage the completion risk than the private sector. When the completion risk is large, sharing the completion risk with the private sector will not bring too much incentive effect, instead, it may cause a large amount of social cost. Therefore, the government should consider the potential efficiency loss when making the risk sharing incentive strategy.

7.2. Under the same incentive loss of the government

7.2.1. The impact of incentive strategies of the government on the investment boundary of the private sector

Under the same incentive loss of the government, the incentive ratio under the risk sharing incentive strategy satisfies $\delta_0 = \frac{rX\left(Q - Q_1\right)}{\eta I}$. Keep the value of basic parameters as constant, Figure 7 shows the relationship between two incentive ratios under different values of volatility of cash flow (σ) and expected rate of return (μ).

From Figure 8, the incentive ratio under the risk sharing incentive strategy (δ_0) increases with the incentive ratio under the tax reduction strategy (δ), and the larger the volatility of cash flow, the larger is the increase rate. The intuition is that the government loss caused by the tax reduction incentive strategy ($Q - Q_1$) is large when the volatility of cash flow is large. However, it displays a reverse U-shape relationship between two incentive ratios when the expected rate of return of the project is relatively large (μ = 0.34), which manifests that when there is a good prospect for the project's profitability, increasing the tax reduction incentive ratio may not necessarily decreases the tax benefits of the government.

Figure 9 depicts the impact of the investment strategy on the investment boundary of the private sector under

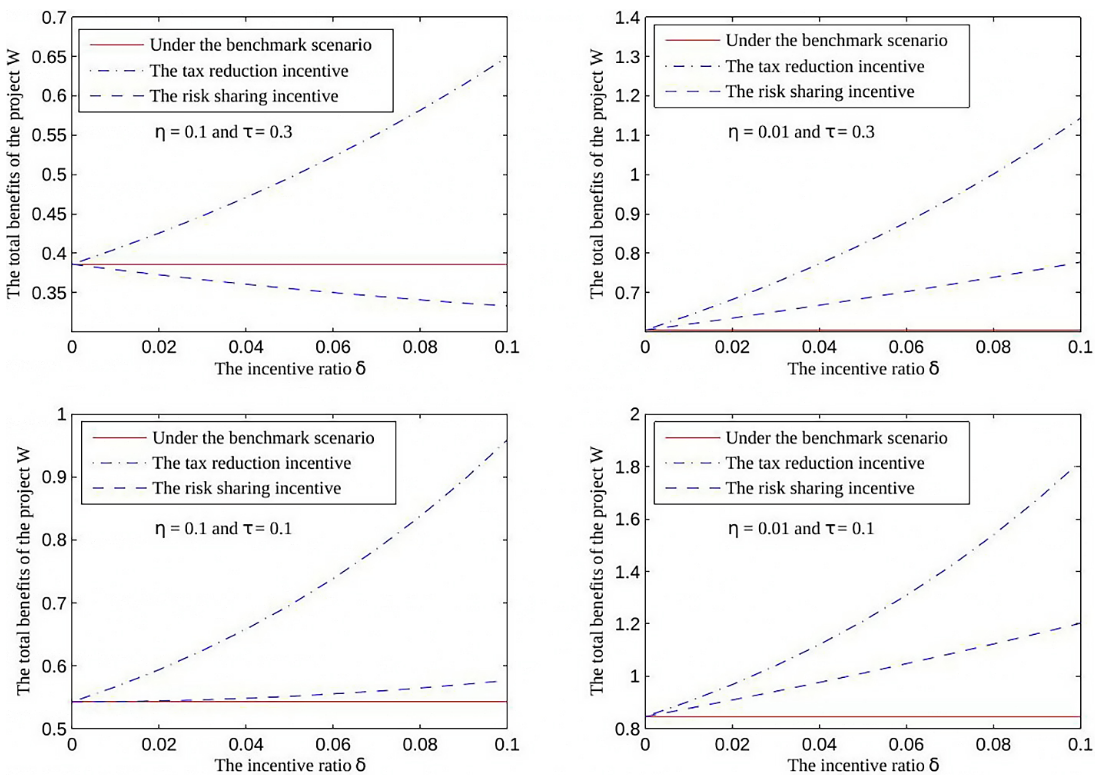

Figure 7. The total benefits of the project

the same incentive loss of the government. The investment boundary of the private sector is lower under the tax reduction incentive than that under the risk sharing incentive when the completion risk is relatively large (η = 0.1). The main reason is that under the same incentive loss of the government, the larger the completion risk, the smaller should be the incentive ratio under the risk sharing incentive, which leads to a smaller incentive effect for the private sector. When the completion risk is relatively small (η = 0.001), the private sector will invest earlier under the risk sharing incentive than under the tax reduction incentive when the incentive ratio is small, while the private sector will invest earlier under the tax reduction incentive than under the risk sharing incentive when the incentive ratio is large. The intuition is that the completion risk is a main concern of the private sector to invest in the PPP project, since the completion risk will affect whether the private sector can get back the investment smoothly. Therefore, even the completion risk is small, a small incentive ratio can have a significant incentive effect for the private sector. However, when the incentive ratio increases to a certain level, the risk sharing incentive will not bring the private sector too many benefits because the completion risk is small. On the contrary, the private sector may get more tax benefits under the tax reduction incentive, so the incentive effect of tax reduction incentive policy becomes larger than the risk sharing incentive policy. Based on the above analysis, it can summarize that the tax reduction incentive strategy is more effective than the risk sharing incentive strategy under the same incentive loss of the government. Interestingly, this result is exactly contrary to the result derived in the scenario under the same incentive ratio.

7.2.2. The impact of the incentive strategies on the total benefits of the project

Figure 10 displays the impact of the incentive strategy on the total benefits of the project under the same incentive loss of the government. It can be found that when the completion risk is relatively large (η = 0.1), the tax reduction incentive strategy improves the total benefits of the project, while the risk sharing incentive strategy decreases the total benefits of the project. Namely, there exists efficiency loss under the risk share incentive strategy when the completion risk is large, which is consistent with the result in the scenario under the same incentive ratio. Besides, it can be found that when the completion risk is relatively small (η = 0.01), although two incentive strategies can improve the total benefits of the project, the total benefits under the risk sharing incentive strategy is larger than that under the tax reduction incentive strategy, which is contrary to the result derived in the scenario under the same incentive ratio.

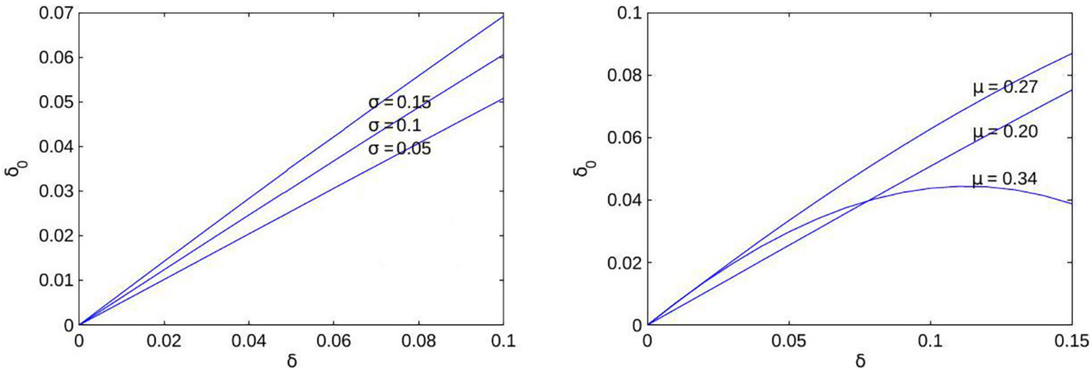

Figure 8. The relationship between two incentive ratios

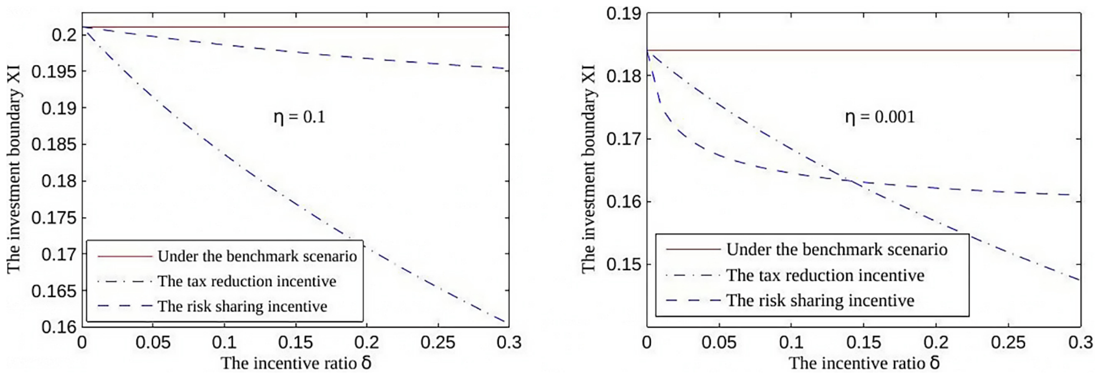

Figure 9. The impact of the incentive strategy on the investment boundary of the private sector (η = 0.1 and η = 0.001, respectively)

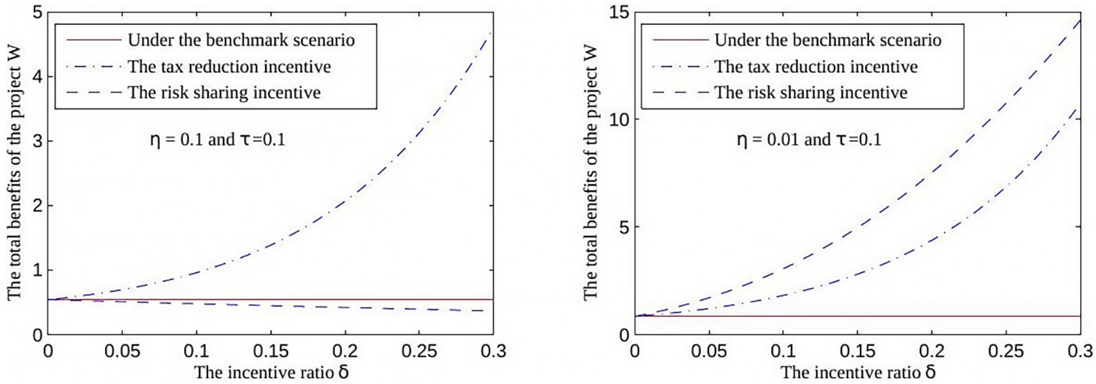

Figure 10. The impact of the incentive strategy on the total benefits of the project

7.3. Under the same incentive effect

7.3.1. The impact of incentive strategy on the benefits of the government

Under the same incentive effect, the incentive ratios under the two incentive strategies δ and δ_0 satisfy the equation $\bar{X}_l^1 = \bar{X}_l^1$. Figure 11 displays the relationship between two incentive ratios when the incentive effect is the same under two incentive strategies. The incentive ratio under risk sharing incentive strategy increases with the incentive ratio under the tax reduction incentive strategy, and the increase rate decreases with the completion risk.

Figure 12 shows the impact of the incentive strategy on the benefits of the government. Under the same incentive effect, it can be seen that when the completion risk is relatively small (η = 0.01), the incentive loss of the government under the tax reduction incentive policy is larger than that under the risk sharing incentive policy; while when the completion risk is relatively large (η = 0.1), the incentive loss of the government under the risk sharing incentive policy is larger than that under tax reduction incentive policy. This result manifests that if government has predetermined the incentive effect, i.e. the government wants the private sector to make investment at a certain time, it is suggested that the risk sharing incentive strategy should be used when the completion risk is relatively small, and the tax reduction incentive strategy should be used when the completion risk is relatively large.

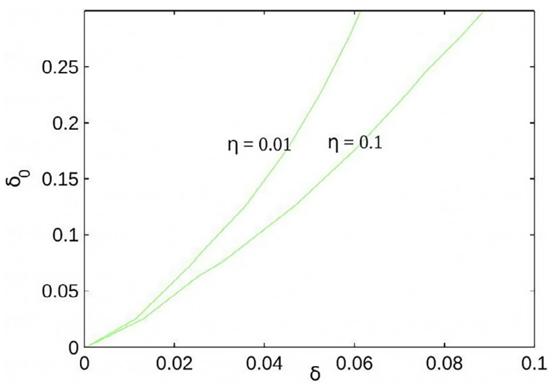

Figure 11. The relationship between two incentive ratios

7.3.2. The impact of the incentive strategy on the total benefits of the project

Figure 13 depicts the impact of the incentive strategy on the total benefits of the project. Under the same incentive effect, it can be seen that when the completion risk is relatively small (η = 0.01), the total benefits of the project is larger under the risk sharing incentive strategy than under the tax reduction incentive strategy; while when the completion risk is relatively large (η = 0.1), the total benefits of the project is larger under the tax reduction incentive strategy than under the risk sharing incentive strategy. This result reflects that when the completion risk is small, the risk sharing incentive policy can bring more benefits

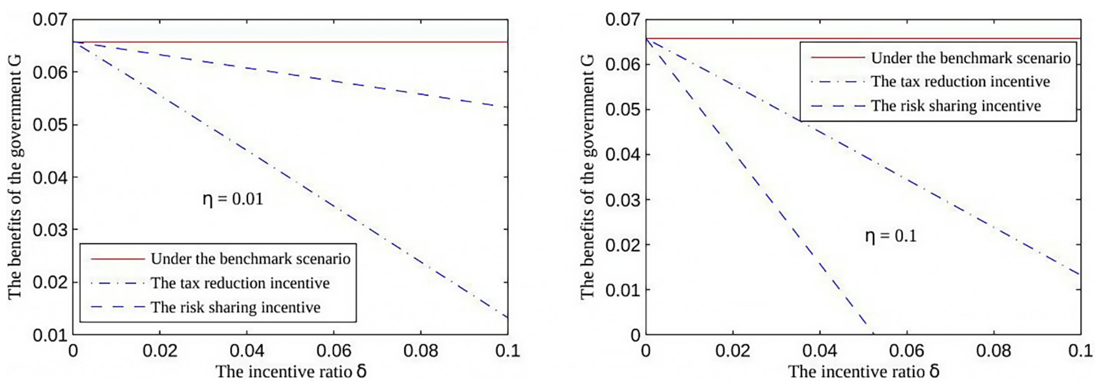

Figure 12. The impact of the incentive strategy on the benefits of the government

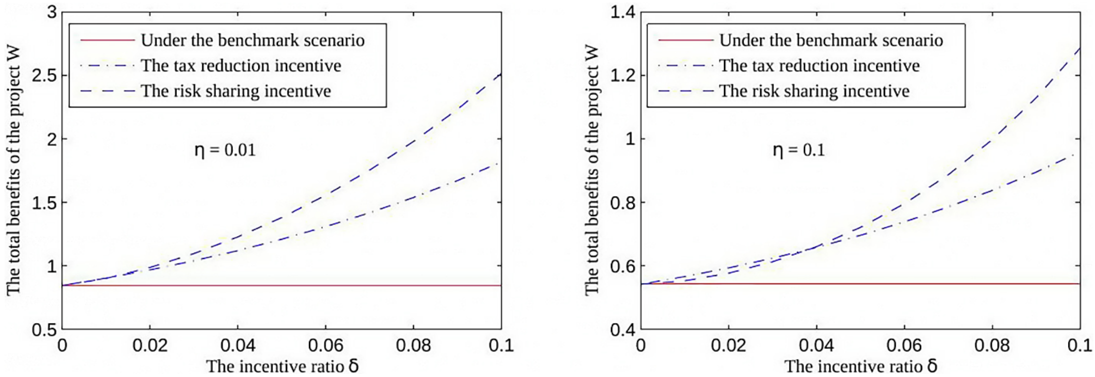

Figure 13. The impact of the incentive strategy on the total benefits of the project

for the project at a smaller cost of the government; while when the completion risk is large, the tax reduction incentive policy can bring more benefits for the project at a smaller cost of the government. Therefore, it is further confirmed that the risk sharing incentive strategy should be used when the completion risk is relatively small, and the tax reduction incentive strategy should be used when the completion risk is relatively large.

8. Conclusions and implications

To make a proper incentive policy, it is critical for the government to know how the incentive policy influences the investment decision of the private sector. This study investigates the investment decision of the private sector under two different governmental support policies: the tax reduction incentive policy and the risk sharing incentive policy. The results manifest that: first, both the tax reduction incentive policy and the risk sharing incentive policy can effectively motivate the private sector to invest in the project; second, the optimal debt level of the project under the tax reduction incentive policy displays a U-shape relationship with the incentive ratio, and the default boundary of the private sector decreases with the incentive ratio, while the optimal debt level of the project and the default boundary of the private sector are free from the influence of the risk sharing incentive policy; third, there may exist efficiency loss under the risk sharing incentive policy when the completion risk is large. Besides, the relative efficacy of two incentive policies is different under different scenarios. First, under the same incentive ratio, the risk sharing policy is relatively more effective than the tax reduction policy. Second, under the same incentive loss of the government, the tax reduction policy is relatively more effective than the risk sharing policy. Third, under the same incentive effect, the risk sharing incentive policy is relatively more effective than the tax reduction policy when the completion risk is small, while the tax reduction incentive strategy is relatively more effective than the risk sharing incentive policy when the completion risk is large.

The implications of our study are mainly twofold. Theoretically, our study can enrich the literature in three ways. First, our study pioneers an analysis of how tax reduction and risk sharing policies affect the investment decisions of the private sector specifically within PPP frameworks, which has not been simultaneously focused on the existing body of knowledge. Secondly, our study introduces the competition factor within infrastructure market into the analysis for the first time, offering new insights into how this factor influence policy efficacy in project management practices. Thirdly, our study employs the concept of relative efficacy from an interdisciplinary perspective in the construction field to evaluate these two government support policies under three different scenarios: equal incentive ratios, equivalent incentive loss for government, and comparable incentive effects. Through these theoretical contributions, the research provides a solid understanding of policy impacts on private investment in PPPs. Practically, this study proposes managerial insights to help the government in making more effective incentive policy. For example, for the governments facing financial constraint and seeking to attract private investment in PPP projects at certain incentive cost, the tax reduction incentive policy should be prioritized. Such policies can motivate the private sector to invest earlier and reach a win-win result for both the government and private sector. For governments aiming to attract private investment in PPP projects with a target incentive effect, the choice of incentive policy should depend on the completion risk. The risk sharing incentive policy is recommended when completion risk is small; otherwise, prioritizing tax reduction incentive policies should be considered. Notably, the governments should be cautious with the risk sharing policy during the decision-making process, as efficiency losses may occur under certain condition. Through these managerial insights, the research can help the government to make more efficient incentive decisions for attracting private investment in PPP projects.

This study can be further extended by integrating some constrains in the model, e.g. the fiscal budget constraints of the government and the debt constrains of the private sector. Besides, the relative efficacy of other kinds of governmental supports, e.g. the government loan guarantee and the minimum revenue guarantee, attracting the investment of the private sector can also be investigated by the framework proposed in this paper.

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Authors declare there are no competing financial, professional, or personal interests from other parties.

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APPENDIX

Proof of proposition 1:

It can be derived that $\frac{d\bar{X}_I}{d\eta} > 0$, so the investment boundary $\bar{X}_I$ increases with the completion risk η. Denote $f(\rho) = \frac{\gamma_1}{\gamma_1 - 1}$, and $g(\rho) = \frac{1+r-\rho-\mu}{1+r-2\rho-\mu}\frac{1+r-2\rho}{1+r-\rho}$, then $\bar{X}_I = \frac{I}{(1-h)B}f(r)g(r)$. It can be derived that $\frac{df(\rho)}{d\rho} > 0$, and $\frac{dg(\rho)}{d\rho} > 0$, so $\frac{d\bar{X}_I}{d\rho} = \frac{1}{(1-\eta)B}\left(f'(\rho)g(\rho) + f(\rho)g'(\rho)\right) > 0$, so the investment boundary $\bar{X}_I$ increases with the completion risk ρ.

Proof of proposition 2:

The benefits of the government can be expressed as $G(X) = QX, Q = \left(\frac{\tau}{r-\mu} - \frac{\tau}{r}P - \frac{\tau\mu}{r(r-\mu)}P^{1-\beta_2}\right)$. $\frac{dG(X)}{d\tau} = \left(\frac{1}{r-\mu} - \frac{1}{r}P - \frac{\mu}{r(r-\mu)}P^{1-\beta_2}\right)X - \tau\left(\frac{1}{r} + \frac{\mu(1-\beta_2)}{r(r-\mu)}P^{-\beta_2}\right)\frac{dP}{d\tau}X$. Since when $\tau = 0, \frac{dG(X)}{d\tau} = \frac{1}{r-\mu} > 0$, and $\frac{d^2G(X)}{d\tau^2} < 0$, there exists a τ^* that makes $\frac{dG(X)}{d\tau} = 0$. Therefore, there exists an optimal tax rate τ^* that makes the benefits of the government maximum.

Proof of proposition 3:

It can be derived that $X_D^1 - X_D = -\frac{r-\mu}{r}\frac{\delta Q}{1+\tau+\delta Q}\frac{\beta_2}{\beta_2 - 1}C < 0$, so the proposition 3 is proven.

Proof of proposition 4:

The optimal debt level C_1^* satisfies $C_1^* = \frac{r}{r-\mu}\frac{1-\tau+\delta Q}{1-\tau}\frac{\beta_2 - 1}{\beta_2}A_1X$. It can be derived that $\frac{dC_1^*}{d\delta} = \frac{r}{r-\mu}\frac{\beta_2-1}{\beta_2}QA_1X\left(1 - \frac{(r-\mu)(1-\alpha)}{r(\tau-\beta_2)(1-\tau+\delta Q) + (r-\mu)(1-\alpha)\beta_2}\right)$. Therefore, when it is satisfied that $\delta \le \frac{(1-\tau)}{Q}\left(\frac{(r-\mu)(1-\alpha)(1-\beta_2)}{r(\tau-\beta_2)} - 1\right)$, $\frac{dC_1^*}{d\delta} \le 0$; when it is satisfied that $\delta > \frac{(1-\tau)}{Q}\left(\frac{(r-\mu)(1-\alpha)(1-\beta_2)}{r(\tau-\beta_2)} - 1\right)$, $\frac{dC_1^*}{d\delta} > 0$. The proposition 4 is proven.

Proof of proposition 5:

Suppose $f(\delta) = \frac{\xi_1}{\xi_1 - 1}$, and $g(\delta) = \frac{1+r+a\delta-\rho-\mu}{1+r+2a\delta-2\rho-\mu}\frac{1+r+2a\delta-2\rho}{1+r+a\delta-\rho}$, then the investment boundary $\bar{X}_I^1$ can be expressed as $\bar{X}_I^1 = \frac{I}{(1-\eta)B_1}f(\delta)g(\delta)$. It can be derived that $\frac{dX_I^1}{d\delta} = \frac{I}{(1-\eta)B_1}\left(f'(\delta)g(\delta) + f(\delta)g'(\delta)\right)$. Besides, it can be derived that $f'(\delta) < 0$ and $g'(\delta) < 0$, so $\frac{dX_I^1}{d\delta} < 0$. Therefore, the investment boundary decreases with the tax reduction ratio δ. It can be seen that δ and a have a symmetrical position in the expression of X_I^1, so X_I^1 decreases with a. A similar process can be used to prove the Proposition 6.

Proof of proposition 7:

When $a = a_0$ and $\delta = \delta_0$ $X_I^2 - X_I^1 = \frac{\xi_1}{\xi_1 - 1}\frac{1+r+a\delta-\rho-\mu}{1+r+2a\delta-2\rho-\mu}\frac{1+r+2a\delta-2\rho}{1+r+a\delta-\rho}I\left(\frac{1-\delta\eta}{(1-\eta)B} - \frac{1}{(1-\eta)B_1}\right)$, so the necessary and sufficient condition that $X_I^2 - X_I^1 > 0$ is $\left(\frac{(1-\delta\eta)}{(1-\eta)B} - \frac{1}{(1-\eta)B_1}\right) > 0$, namely, $\eta < \frac{1}{\delta}\frac{B_1 - B}{B_1}$. Therefore, the proposition 7 is proven.

Proof of proposition 8:

When $a = a_0$, $\delta = \delta_0$ and $\eta = \frac{B_1 - B}{\delta B_1}$, it is obvious that $X_I^1 = X_I^2$. Under these conditions, $G^2(X) - G^1(X) = (Q - Q_1)X - \frac{\eta\delta I}{r}$. Therefore, to satisfy $G^2(X) > G^1(X)$, it needs to satisfy that $I < \frac{(Q-Q_1)B_1 rX}{B_1 - B}$. On the contrary, to satisfy $G^2(X) \le G^1(X)$, it needs to satisfy that $I \ge \frac{(Q-Q_1)B_1 rX}{B_1 - B}$. The proposition 8 is proven.

Proof of proposition 9:

Under the same incentive loss of the government, it needs to satisfy that $G^1(X) = G^2(X)$, from which it can be derived that $\delta_0 = \frac{rX(Q-Q_1)}{\eta I}$.