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DETERMINING CONCESSIONARY ITEMS FOR "AVAILABILITY PAYMENT ONLY" PPP PROJECTS: A HOLISTIC FRAMEWORK INTEGRATING VALUE-FOR-MONEY AND SOCIAL VALUES

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Abstract. Public-private partnerships (PPPs) have been widely applied in infrastructure development around the world. However, reasonable concessionary items are critical to compromise interest conflicts between government agencies and sponsors to ensure project success. A broad literature review centering on PPP transaction structuring revealed two significant research gaps: (1) a lack of attention to the 'availability payment only' (APO) funding method and (2) negligence of the public side's perspective in determining concessionary items. The research objective was to develop a methodological framework for determining concessionary items in APO PPP projects while considering the interests of the public side. This study proposed a value-for-money (VFM) and social values integrated framework which accommodates discounted cash flow (DCF) analysis, bargaining game modeling, and multi-objectives decision-making (MODM). This framework enables a decision-making process based on both an indifferent feasible interval of concessionary items under a discount rate agreed upon by both parties and an optimal set of concessionary items. Additionally, results of a sensitivity analysis indicated that project construction profit can significantly affect feasible and optimal concession items, and the optimal concession period is less sensitive to changes in risk allocation. The application of proposed model indicated that this paper successfully provides a methodology for determining a feasible interval and an optimal concession items group tailored to APO PPP projects. This study paves the way towards a platform for the public and private partners to jointly and quickly come up with sound PPP concessional items in light of the win-win principle, particularly under the APO funding mechanism.

Keywords: public-private partnerships, value allocation, optimal concessionary items determination, VFM and social value integration, availability payment only (APO), multi-objectives decision-making (MODM), bargaining game model.

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1. Introduction

Public-private Partnerships (PPPs) have been widely adopted as a mechanism for procuring infrastructure under pressure of rampant fiscal shortfalls (Bao et al., 2018; Osei-Kyei & Chan, 2015). Crucial to the success of PPPs is a high level of cooperation between the public and private parties (Osei-Kyei & Chan, 2015). Such complex concession based contractual arrangement requires that key concessionary items be properly determined at the front end of a PPP project, such as concession period and tariff/subsidy level. Concessionary item in PPP projects refers to a condition or term that can decide the project life-cycle cash flow generation, acquisition, and allocation, formulated jointly by the public and private stakeholders to the project. For example, the concession period is a concessionary item for any type of PPP projects. Other items, such as the unit price of licensed products (i.e., the concession price), the return on invested capital (ROIC), and the minimum revenue guarantee (MRG), vary depending on the specific characteristics of the project. In addition, in a project, the concession items are combined and used together. These decision-making issues about concessionary items determination remain as hot topics in the construction and project finance domain.

In China, the PPP market since 2014 has been booming, with a total of 10,363 projects recorded, at an agglomerate investment of 16.8 trillion yuan as of November 2022 (China Public Private Partnerships Center, 2022). Of these, "availability payment only" (APO) projects (i.e., where return to investors comes solely from government subsidy without any user remittance) account for 35.1% by number, according to the Monthly Report for November 2022 of National PPPs Projects Development in China (China Public Private Partnerships Center, 2022). APO PPP projects refer to those in which the revenue investors gain derives entirely from availability-based payment by the local government. In China's APO PPP projects, concessionary items usually include ROIC, return on operation and maintenance (ROOM), and, of course, the concessionary period. APO PPP projects are usually municipal roads, public parks, bridges, tunnels, ecological and environmental protection facilities where it is physically or legally impossible to charge end users. Furthermore, during the operational period, the government shall provide APO PPP project investors with returns based on the pre-agreed ROIC and ROOM items specified in the contract. A key distinction between APO PPP and other projects lies in the allocation of demand risk, which is borne by local governments in APO PPP and transferred to investors in other PPP projects. Strikingly, given that governments cannot directly extract cash inflow from those projects, existent methods that determine concession items based on apportioning of project revenue become inapplicable. This distinct risk allocation necessitates the exploration of an alternative approach for determining concessionary items in APO PPP projects, as project value does not rely on fluctuating revenue charges from end users.

Value for money (VFM) is a well-accepted criterion for promoting PPP projects in many countries (Cui et al., 2019; HM Treasury, 2006; Martins et al., 2014). VFM evaluation consists of qualitative and quantitative appraisals. Concessionary items are core parameters when calculating the quantitative VFM value (Ministry of Finance, 2014a), which is the difference between the cost of the public sector comparator (PSC) and the private shadow bid (PSB) price. While sponsors pursue financial gains in a PPP projects, governments strive to maximize their VFM. It may be of great potential to examine the determination of proper concessionary items of APO PPP projects through the lens of VFM.

Generally, PPP is a long-term cooperation between the public and private sectors in the provision of public products or services, in which both sides share risks and benefits. Few studies, however, comprehensively discussed the financial, economic and social values of a PPP project associated with its key concessionary items. Net present value (NPV) and modified NPV methods remain the mainstream focus, implying that PPP project benefits are fairly understood in terms of financial and economic values. By contrast, in APO projects, both social and VFM values are the key benefits to government, which are contingent on concessionary items. Additionally, a higher stake of the government in the initial stages of a PPP project may lead to a reduction in the investor's share during the operational period (Sharafi et al., 2022). These issues point to two significant research questions, as follows: (1) How are values of an APO PPP project to be identified, evaluated and distributed? (2) How are key concessionary items of APO PPP projects to be determined?

This paper therefore aims to develop a holistic framework to answer the questions. This paper proposed a valuation model based on discounted cash flow (DCF) analysis integrating VFM and social values to identify and evaluate project value. Subsequently, the bargaining game modeling was adopted to distribute project value to the government and investors. Finally, a multi-objectives decision-making (MODM) model provided an approach that determining key concessionary items of APO PPP projects. The remainder of this paper is organized as follows. Section 2 presents a literature review. Section 3 shows the methodology followed by this paper. Section 4 develops the valuation models and pricing approach. Section 5 presents an application of proposed model on a real case. Section 6 develops a discussion between the findings of this paper and related literature. Finally, the conclusions are presented.

2. Literature review

2.1. Value of PPP projects

How are concessionary items of a PPP project determined by the allocation of various values has not been thoroughly studied in the construction and project finance domain, though Wang et al. (2018) highlighted its importance. Project value can be defined as the quotient between benefits and costs, or alternatively, between the satisfaction of needs and the use of resources (Morris, 2013). Value varies by different parties to a project and their situational perspectives (Laursen & Svejvig, 2016). Specifically, value in PPPs is defined as the sum or entirety of benefits obtained by various stakeholders from the collaboration (Kivleniece & Quelin, 2012). Therefore, we define:

$$V_{Proj} = \sum_{j} V_{j}, \tag{1}$$

where V_{Proj} indicates the absolute value of a PPP project for which all stakeholders work together. V_j represents the value for stakeholder j. The project value will ultimately be obtained by one or several stakeholders (Laursen & Svejvig, 2016). Equation (1) only presents a conceptual framework, which signifies that this paper assumes theoretically that V_{Proj} encompasses the cross value generated by the collaboration of diverse stakeholders. In the detailed model, the quantifiable cross value will be categorized into V_j for one or certain stakeholders if they are the beneficiaries of the cross value. For PPP projects, there are two dominant stakeholders, the government (public sector) and investor (private sector) (Liu et al., 2022). Thus, when stakeholder j is government or investor, we have V_G or V_I, respectively. End users are also critical stakeholders in PPPs, and the value for them can also be defined in Eqn (1). However, to simplify the valuation model, we incorporate the end users' stake as part of the government's value. The rationale is that social value produced by the government and investor collaboration should benefit the general public (Caldwell et al., 2017).

2.2. Social value and value-for-money in PPP projects

Social values should be accounted for in the design of the initial contract (Viegas, 2010). Social welfare is the proper criterion for evaluating the social value of PPPs (Boardman & Vining, 2012). With the evolution of social preferences, socially desirable specifications of services offered by PPP projects can be expected to shift. In one particular study, social welfare has been identified as a goal in PPP contracts for utilities (Moore et al., 2017). Maximizing social value is a responsibility of the government, while investors seek maximization of financial gains (Moore et al., 2017). Wang et al. (2022) put forward a pricing method for surface water loop heat pump PPP projects to maximize social welfare under conditions of least subsidy constraint. This study shows that the government aims at two goals equally: social value maximization as well as government-payment minimization. Some scholars find that in highway PPP projects public social value should be reflected in their valuation (Mochon et al., 2022). Similarly, in dealing with the different goals of the two main PPP parties, Repolho et al. (2016) proposes an optimization framework based on the maximization of social welfare benefits. Boardman and Hellowell (2017) pursue this social value maximization goal using a VFM analysis approach. Li et al. (2018) highlights that social welfare should be considered in determining financial compensation strategies of PPP projects.

VFM is a basic concept generally recognized in public administration (Glendinning, 1988). The pursuit of the three goals of Economy, Efficiency, and Effectiveness (3E) lies at the core of VFM (Park, 2014). VFM principles have been widely applied to ensure PPP success across different countries (Kweun et al., 2018). Evidence shows that the application of VFM method alters PPP projects' socio-economic and community impacts (Siemiatycki & Farooqi, 2012). Quantitative VFM is usually calculated as the difference between PSC and PSB value. Although scholars have different views on the composition of PSC and PSB values, it is generally agreed that the VFM for PPP projects is the NPV of the total cost in the PPP model less than that in traditional public procurement (Burger & Hawkesworth, 2011; Farquharson & Yescombe, 2011). VFM evaluation methods are not mature yet, where they in general only account for financial and economic factors. Some scholars argue that VFM analysis should also consider social parameters in order to expand the evaluation framework and promote social value increases in PPP projects (Agarchand & Laishram, 2017; Martins et al., 2014). This study intends to combine both VFM and social values to determine key concessionary items.

2.3. Concessionary item determination of PPP projects

Key concessionary items determining a PPP project's structuring and performance are contingent on the funding type, i.e., Availability Payment Only (APO), Viability Gap Funding (VGF), or User Charge Only (UCO) (Ministry of Finance, 2014b). A summary of existing literature on concessionary items is summarized in Table 1. Early on, scholars focused on concession period determination regarding highways, toll roads, bridges, and other transportation projects. Those projects' funding type was mainly UCO (Khanzadi et al., 2012; Shen et al., 2007; Yu & Lam, 2013). It shows that concession period length has received the most attention as a key concessionary item. Next to it is government subsidy, and several articles examined how the subsidy amount can be optimized (Lv et al., 2020; Sharafi et al., 2022; Sharma & Cui, 2012). The determination of more than one concessionary item simultaneously is relatively more complex, but researchers have already made progress in this direction (Bayat et al., 2019; Iyer & Sagheer, 2012; Sharafi et al., 2022). For instance, a simulation-based optimization model was developed to simultaneously determine concession period, concession fee, debt ratio, interest rate, and tariff (Liou et al., 2011). By defining users' time savings as social welfare, the paper developed a unique approach where the social welfare was calculated by subtracting the ticket costs of using the cable car from the passengers' time-saving value resulting from cable car use (Liou et al., 2011). This calculation, however, applies only to cable car and similar projects with quantifiable benchmarks (Liou et al., 2011). For determining concessionary items, scholars have tried various methods, and it showed that game model is the most popular one (see Table 1), followed by MODM and simulation. Method selection depends not only on methodological comparisons but also on project-specific characteristics. Methods such as the game model, MODM, and simulation-based methods each have their advantages and disadvantages, as well as their scope of application. For example, the simulation-based method is particularly effective in dealing with demand risk and its fluctuations (Ullah et al., 2016; Zhang, 2009). The bargaining model plays a crucial role in capturing and modeling the interest conflicts between multiple stakeholders in PPP projects (Bayat et al., 2020; Jin et al., 2020a). However, in these methodological academic articles, the detailed application of the aforementioned methods is typically demonstrated through case studies based on UCO PPP projects. In fact, the bargaining model can be employed to allocate project values not only in UCO but also in APO PPP projects. As for MODM, it is a versatile method in this domain since it facilitates the identification of an optimal solution to proposed optimization models that reconcile diverse stakeholders' interests (Guo et al., 2023).

Table 1. A summary of existing literature on determining concession items

References	CIs	Applicable project types			Stakeholders' objectives			Key methods adopted	Type of results
		APO	VGF	UCO	Governments	Investors	Other stakeholders		
Bakatjan et al. (2003)	CS	×	–	✓	NC	Maxi. IRR	NC	Linear programming	A specific value at different constraints
Ng et al. (2007)	CL, Tariff, IRR	×	–	✓	Mini. CL	Maxi. IRR	Mini. tariff (for users)	Fuzzy simulation	A specific value set at three risk scenarios
Shen et al. (2007)	CL	×	–	✓	Maxi. FR	Maxi. FR	NC	Bargaining game	An interval
Islam and Mohamed (2009)	CL, CP, CS	×	–	✓	NC	Maxi. utility	NC	MODM & GA	A specific value set
Liou et al. (2011)	CP, CL, CS, tariff, FIR	×	–	✓	Maxi. NEB	Maxi. FNPV	Mini. financial risk (for lenders)	MODM & GA	A specific value set at Pareto-front
Iyer and Sagheer (2012)	Grant ratio, CS	×	✓	✓	NC	Maxi. FNPV & Mini. tender	NC	MODM & GA	A specific value set
Khanzadi et al. (2012)	CL	×	–	✓	NC	NC	NC	Fuzzy system dynamics	An interval
Sharma and Cui (2012)	CL, MAP	×	✓	×	Mini. expenses	Maxi. FR	NC	SDP & MODM	An upper limit value set
Yu and Lam (2013)	CL	×	×	✓	FNPV > 0	FNPV > (Inv* ERR)	NC	Monte Carlo simulation	A group of alternatives
Carbonara et al. (2014)	CL	×	×	✓	Maxi. FR	Maxi. FR	NC	Monte Carlo simulation	A specific value at different probabilities
Bao et al. (2015)	CL	×	×	✓	Maxi. FR	Maxi. FR	NC	Bargaining game	A specific value at different probabilities
Sun and Zhang (2015)	MRG and Royalty	×	×	✓	Mini. (MRG-Royalty)	NC	NC	MODM	A specific value set
Xu et al. (2017)	CL	×	×	✓	Maxi. utility	NC	NC	DSP & MODM	A specific value
Feng et al. (2018)	CL, CP, CS, subsidy	×	×	✓	Mini. expenses	Maxi. FNPV	NC	MODM	A series of viable concessionary items
Sun et al. (2019)	CS	×	×	✓	NC	Maxi. IRR	Maxi. DSCR (for lender)	MODM	A specific value at different scenarios
Bayat et al. (2019)	CL, CS	×	×	✓	Maxi. FR	Maxi. FR	Maxi. DSCR (for lender)	Trilateral bargaining game	A specific value at different scenarios
Jin et al. (2019)	CL	×	✓	–	NC	NC	Mini. financial risk (for project)	MODM & Monte Carlo simulation	A specific value
Bayat et al. (2020)	CL, CS	×	×	✓	Maxi. FR	Maxi. FR	Maxi. DSCR (for lender)	Bargaining game	An interval
Yuan et al. (2019)	CP, subsidy	×	✓	–	Maxi. satisfaction	Maxi. satisfaction	Maxi. satisfaction (for users)	System dynamic simulation	Adjustments of CP and subsidies
Jin et al. (2020b)	CL	×	×	✓	Maxi. FR	Maxi. FR	NC	Bargaining game	A specific value at different probabilities
Shang and Abdel Aziz (2020)	Payment assignment	×	✓	✓	Maxi. social welfare	Maxi. FR	NC	Stackelberg game	NC
Jin et al. (2021)	CL and MRG	×	✓	–	Maxi. FR	Maxi. FR	NC	Bargaining game & Monte Carlo simulation	A specific value at different scenarios
Sharafi et al. (2022)	CL, Tolls, subsidies	×	✓	✓	Maxi. social welfare	Maxi. FR	NC	Bargaining game	A specific value at different scenarios
Alghamdi et al. (2022)	CL, CP, CS, subsidy	×	✓	–	Mini. expenses	Maxi. FNPV	Mini. CP and Mini. CL (for users)	MODM & GA	A specific value

Note: CIs – Concession Items; NC – Not Considered; Maxi. – Maximizing; Mini. – Minimizing; CS – Capital Structure; IRR – Internal Rate of Return; CL – Concession Period Length; CP – Concession Price; GA – Genetic Algorithm; FIR – Financing Interest Rate; FR – Financial Return; NEB – Net Economic Benefits; FNPV – Financial NPV; MAP – Maximum Annual Payment; SDP – Stochastic Dynamic Programming model; Inv – investor's capital investment; ERR – Expected Return Rate; MRG – Minimum Revenue Guarantee; DSP – Discrete Stochastic Process model; DSCR – Debt Service Coverage Ratio.

2.4. Research gaps

There are two clear gaps in the existing literature. Firstly, there is a lack of understanding of determination of key concessionary items with regard to APO PPP projects. Secondly, there is an inadequate consideration of the government's perspective upon the subject matter.

As shown in Table 1, none of the studies focused on APO PPP projects. In APO projects, ROIC and ROOM are widely adopted concessionary items because the subsidy is equivalent to the whole return the government offers investors during the construction and operation period. Compared with UCO projects, cash flow characteristics of APO projects are highly different. In APO projects, uncertainty of cash inflow is related to infrastructure availability, while it depends on market demand in UCO projects. Quite a few articles proposed methods suited for UCO projects rather than APO projects to determine concessionary items. For instance, a multi-objective optimization model is presented using discounted cash flow method to determine the concession period, concession price, capital structure, and government subsidy (Feng et al., 2018). However, the revenue function equal to concession price times service demand adopted in this paper does not apply to APO projects. The determination models suitable for VGF projects adopting mixed return mechanisms also have compatibility limitations for APO projects. One reason is simply that existing studies side-step the topic of determining ROIC and ROOM, while the expected ROIC serves as an input parameter determined in advance (Khanzadi et al., 2012; Sharma & Cui, 2012). Moreover, the model of Jin et al. (2019) takes the stochastic traffic volume as the modeling base point and the ROOM distribution as the input variable to calculate the optimal concession period. However, the model does not hold if the toll fee revenue assumption is removed. For similar reasons, the model to determine concession period and MRG proposed by another article is also unsuitable for APO projects even if user revenues are removed (Jin et al., 2021). Some scholars proposed a model to optimize the government payment amount corresponding to different performance objectives of a PPP project, and the disadvantage of this model is that the concession period needs to be given in advance (Shang & Abdel Aziz, 2020). Tolls, concession length, and government subsidies are also provided by Pareto optimization based on the bargaining game model (Sharafi et al., 2022). However, in this paper the model is developed for contract readjustment, where determining concessionary items is just a by-product.

Table 1 also demonstrates that no study took VFM into account as one of the government objectives when deciding on concessionary items, even though several publications consider social benefits in addition to financial returns (Shang & Abdel Aziz, 2020; Sharafi et al., 2022). Many studies account for stakeholders' objectives in setting concessionary items in PPP projects (Alghamdi et al., 2022; Iyer & Sagheer, 2012; Jin et al., 2019; Liou et al., 2011; Sun et al., 2019). A range of studies consider a single side of the partnership in regards to concessionary items: the government versus investors (Bakatjan et al., 2003; Iyer & Sagheer, 2012; Sun et al., 2019; Sun & Zhang, 2015; Xu et al., 2017). This is contrary to the collaborative imperative of PPPs. Scholars then commenced a series of studies considering interest balance among parties in PPP projects. Most prefer to use financial returns as targets for investors or the government (Bao et al., 2015; Bayat et al., 2019, 2020; Carbonara et al., 2014; Jin et al., 2020b; Shen et al., 2007). It may be acceptable to assume the maximizing of financial return as the primary objective of investors in PPP projects, but the government's objectives go beyond that. Social welfare is at least an indispensable goal for the government (Liou et al., 2011; Shang & Abdel Aziz, 2020; Sharafi et al., 2022). A method ensuring cost savings for the public sector (i.e., minimizing expenses) and financial stability for the private sector simultaneously was developed for determining concessionary items based on a stochastic dynamic programming model (Sharma & Cui, 2012). Moreover, VFM should be the ultimate pursuit of governments in PPP projects, which is obviously neglected in literature. Though Yuan et al. (2019) argued their model embraced VFM performance, it only considered one facet of VFM, i.e., stakeholders' satisfaction. Moreover, their model was applied to adjustment rather than determination, meaning the initial price and subsidy should be fixed in advance (Yuan et al., 2019). A recent article adopted multi-objective optimization models for PPP agreements in which four objective functions emphasized the importance of enhancing NPV, reducing expenditure, and shortening concession period (Alghamdi et al., 2022). The model proposed by Alghamdi et al. (2022) may enhance socio-economic optimization objectives, but does not take realization of VFM goals into account.

3. Methodology

The methodology of this study consists of three steps as shown in Figure 1.

A valuation model based on the DCF method was first developed to identify the value of APO PPP projects to the government as well as investors. The time value of capital must be acknowledged in valuing APO PPP projects (Feng et al., 2023). Thus, the DCF method serves as the basis for developing valuation models for the government and investors alike (Swanson & Sakhrani, 2020). The assessment of PPP project value involves projecting into the future, based on several assumptions as follows:

1. The duration of construction period is predetermined.
2. The concession period is considered a discrete value in years.
3. The general public interests are aimed at by governments as part of their value pursued. The total investment merely consists of equity and debt (no mezzanine).
4. The interest rate is a pre-assumed acceptable figure of lenders. The lenders cannot provide an exact

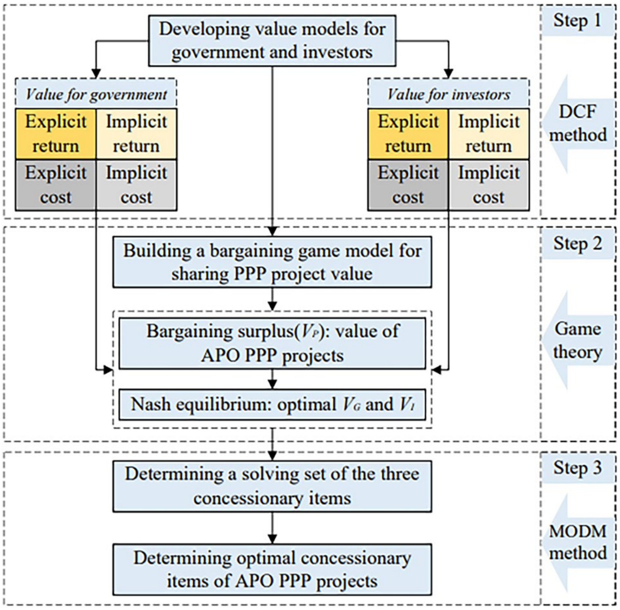


Figure 1. Research steps

interest rate for a project that has not yet contracted in China's PPP practice, but it is reasonable to assume an acceptable rate according to the project particulars and general situation.

5. Debt is paid back in equal annual installments, and the bankability criteria is assumed to be met. This assumption is based on common practices. Debt service is still undertaken by the project company for sure. There is a back-to-back arrangement between the government, investor, and bank, where government subsidy is so calculated that it covers 1) the equity and a return claim on it; 2) the debt and its interest. Hence the investor cannot expect any sort of "interest spread". It therefore looks as if the government would undertake debt service, but as a matter of fact, debt service is the investor's contractual obligation. The investor has to repay its debt to the bank even if the government holds back its subsidy in certain circumstances. In other words, the bankability of APO projects depends on the government's payment ability rather than on user revenues as in UCO projects. Future payments for PPP projects will be included in the medium and long-term budgets of local governments. Debt service can therefore be taken as guaranteed by the government.
6. The construction profit rate is an estimated value based on investors' construction capability and project type, which is given in advance.

Then, a finite-horizon bargaining game model was adopted to solve value allocation. After the partners allocated the value of APO PPP projects, the backward induction method could be used to derive a solution set of concessionary items. Nash posited a bargaining solution to the two-person bargaining problem through an axiomatic proof, described as the Nash bargaining equilibrium solution (Nash Jr, 1950). Infinite-horizon bargaining, an extension of the bargaining game model conducted over a limited period, was proposed by Rubinstein (Osborne & Rubinstein, 1994). His contribution lies in introducing the discount factor, which corresponds to the patience of participants. The bargaining game model is suited to a mathematical analysis of allocation problems under conditions of conflict of interests (Bayat et al., 2019). It also has high applicability in the area of PPPs because PPPs consist of partners with shared interests. The bargaining model provides an analytical and systematic framework for solving the distribution of PPP values among partners (Bao et al., 2015; Jin et al., 2020b; Li et al., 2017). The utilization of this method is based on the following considerations: 1) For APO projects, where cash flows are not obtained directly from end-users, the distribution of values between the government and investors can be modeled using the alliance profit distribution scenario applicable to bargaining games. 2) In the case of investor-initiated projects, even if they have not entered the tendering stage, the negotiation process between the government and investors can still be viewed as a bargaining game scenario, given the significant involvement of investors in the early stages of the project. 3) In government-initiated projects, finding potential investors is a crucial step, and thus, when determining the project's return level, the government must consider the value that investors can derive from the project. For APO projects, this implies that while the proposed value allocation is led by the government, the (potential) demands of investors still play a role in the process. In this regard, the bargaining game serves as a simulation of this process rather than a real scenario that unfolds. In a typical two-person bargaining model, if both players have infinite patience, the game can continue until both players are satisfied, or the negotiation breaks down. However, both players would consider the value of time in a real-world bargaining situation, and prefer to make a deal as soon as possible. Thus, for both parties in a PPP project, the total project value to be shared will decrease over time. δ_G and δ_I represent the discount factors, reflecting the patience of both players. δ_G and δ_I mean that one dollar of the project value will become δ_G and δ_I dollars in the next period for the government and the investors, respectively, where $0 < \delta_G < 1.0 < \delta_I < 1$. In this research, the bargaining game model was adopted to show how the government and investors allocate project values.

Finally, optimal concessionary items of APO PPP projects can be obtained by utilization of the MODM method. The MODM method is an essential branch of computational mathematics. It is used to describe the optimization problem, which assesses the value of decision variables within a reasonable range of matters under certain constraints in order to make the objective function achieve optimization (Sun & Zhang, 2015). In this study, the MODM method was applied to solve the win-win optimization problem, subject to the decision variables in the solution set given by the bargaining model.

4. Model description

4.1. Developing valuation models for the government and investors

As Figure 2 and Figure 3 show, a dichotomy logic was adopted to develop valuation models for the government and investors in PPP projects. Returns and costs for both partners were divided into explicit and implicit. The valuation frameworks for the government and investors are based on the same logic and invoke the value creation process. The value for a stakeholder can be defined as the quotient of benefits/costs or the difference of returns/costs (Morris, 2013). This study adopts the latter definition. In PPP projects, the government and investors input their capital and resources (i.e., costs), and obtain returns coming from the project. Thus, the values acquired by the partners from the project can be calculated on the basis of returns minus costs. We divided the returns and costs into two categories, namely explicit and implicit. For investors, explicit returns and costs can be easily defined

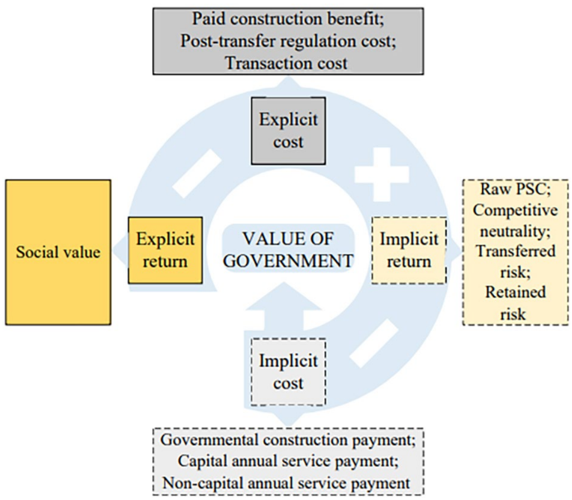


Figure 2. Valuation model for the government

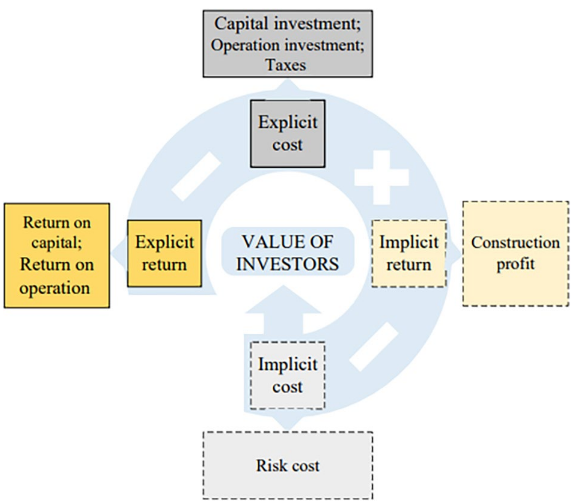


Figure 3. Valuation model for investors

through cash flows. The elements of explicit returns and costs refer to aspects widely recognized in the financial analysis of PPP projects. Construction profits and risk costs are considered implicit returns and costs, respectively, as they are not included in standard financial models. For the government, the VFM value represented explicit benefits (i.e., explicit returns minus the costs) in APO PPP projects, as during the concession period, they do not receive any explicit cash inflows, whereas they need to pay investors. The social value created by the project deserves to be considered as an implicit return for the government, as the agent of the general public. The implicit cost refers to those expenses that the government needs to pay but are not reflected in explicit costs. It should be pointed out that the division of explicit and implicit returns and costs is relatively complete, but the various items included in them are simplified. This categorization of those items as implicit or explicit can impact the calculation process for V_G and V_I, and thus influence concessionary item determination.

4.1.1. Valuation model for the government

According to the above reasoning process of valuation logic for the government's value, we can define:

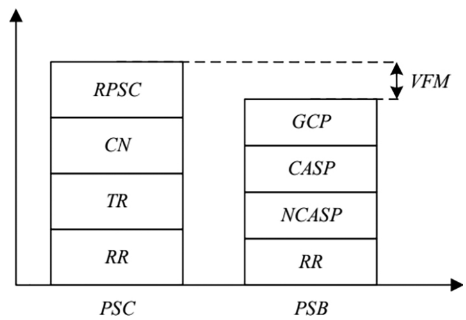
$$V_G = ER_G + IR_G - EC_G - IC_G, \quad (2)$$

where V_G means value for the government in a PPP Project, ER_G, IR_G, EC_G, IC_G represent the government's discounted explicit return, implicit return, explicit cost, and implicit cost, respectively.

In an APO PPP project, the government does not have explicit cash inflow anymore. Generally, most countries apply VFM in evaluating government benefits, where the quantitative part is defined as cost savings in the PPP model compared with in traditional procurement model. So, the difference between explicit return and cost could be represented instead of V_{VFM}.

As the Figure 4 shows, Quantitative VFM value, that is V_{VFM}, can be calculated by Eqn (3):

$$V_{VFM} = PSC - PSB. \quad (3)$$



Note: RPSC, CN, TR, RR, GCP, CASP, and NCASP represent raw PSC, competitive neutrality, transferred risk, retained risk, governmental construction payment, capital annual service payment, and non-capital annual service payment, respectively

Figure 4. Quantitative VFM value

Then, we have

$$ER_G - EC_G = V_{VFM} = \mathrm{RPSC} + \mathrm{CN} + \mathrm{TR} + \mathrm{RR} - \left(\mathrm{GCP} + \mathrm{CASP} + \mathrm{NCASP} + \mathrm{RR}\right) = \left(\sum_{n=1}^{t_1} \frac{CC_n}{\left(1+i_G\right)^n} + \sum_{n=1+t_1}^{t_1+t_2} \frac{OC_n}{\left(1+i_G\right)^n}\right) + \left(\sum_{n=1}^{t_1+t_2} \frac{TAX_n}{\left(1+i_G\right)^n}\right) + \left(\sum_{n=1}^{t_1+t_2} \frac{\sum_k RCI_n^{(k)}}{\left(1+i_G\right)^n}\right) - \left(\sum_{n=1}^{t_1} \frac{CC_n \times PoCI \times PoGI}{\left(1+i_G\right)^n}\right) - \left(\sum_{n=1+t_1}^{t_1+t_2} \frac{CC \times PoCI \times \left(1-PoGI\right) \times r_\alpha \times \left(1+r_\alpha\right)^{t_2}}{\left[\left(1+r_\alpha\right)^{t_2}-1\right]\left(1+i_G\right)^n} + \sum_{n=1+t_1}^{t_1+t_\beta} \frac{CC \times \left(1-PoCI\right) \times r_\beta \times \left(1+r_\beta\right)^{t_\beta}}{\left[\left(1+r_\beta\right)^{t_\beta}-1\right]\left(1+i_G\right)^n}\right) - \left(\sum_{n=1+t_1}^{t_1+t_2} \frac{OC_n \times \left(1+r_m\right)}{\left(1+i_G\right)^n}\right), \quad (4)$$

where CC_n and OC_n indicate annual construction cost and annual operation cost in year n. i_G is the discount rate for government. t_1, t_2 represent the construction period and the operation period. *PoCI* and *PoGI* represent the equity ratio and the government share ratio, respectively. The total construction cost of the project consists of equity and debt funds, with most of the equity funds provided by investors. To enhance the attractiveness of the projects, the government sometimes funds the project through equity. These funds, known as GCP, have a value equal to the project construction cost multiplied by the equity ratio and then multiplied by the government's share. TAX_n represents annual taxes in year n. $RCI_n^{(k)}$, being the risk cost of investors (transferable risk) for risk k in year n. According to Ministry of Finance (2015a), the risk cost can be calculated using the proportional method, scenario analysis method, and probability method. This study uses the scenario analysis method to calculate risk cost, which is also the most commonly used method in practice. The transferable risk cost can be calculated by following these steps: 1) Establishing a risk assessment panel of experts, 2) Evaluating the risks by the panel, who will be asked to estimate the risk consequences in favorable, basic, unfavorable, poor, and worst-case scenarios and estimate the probability of occurrence for each scenario, and 3) Calculating the transferable risk cost (risk cost equals to the risk consequence multiplied by the probability of the consequence occurring). r_α and r_m represent return on invested capital (ROIC) and return on operation and maintenance (ROOM). r_β and t_β represent interest rate and term of the debt.

The implicit return for the government refers to social value created by the project. The implicit cost refers to those expenses that the government needs to pay but are not reflected in explicit costs. Then, we have

$$IR_G - IC_G = \lambda CC^a OC^b - \left(\sum_{n=1}^{t_1} \frac{CC_n \times r_{bc}}{\left(1+i_G\right)^n} + \sum_{n=1}^{l} \frac{TRC_n}{\left(1+i_G\right)^n} + \sum_{n=1}^{l} \frac{RC_n}{\left(1+i_G\right)^n}\right), \quad (5)$$

where IR_G represents social value earned by the government as an agent of the end users (i.e., implicit return for the government from the PPP project). In Eqn (3), λ represents the ability to transform investment into social value (λ > 1), which depends on project characteristics, investors' ability, and partnership quality. *a* and *b* represent the output elasticities of construction and operation investments, respectively. *CC* represents the total construction investment. *OC* represents the total operation cost during the project's lifespan. r_{bc} represents the profit margin of construction. The government pays construction benefits to investors, especially in APO PPP projects. However, the amount of construction benefits is not factored into the VFM calculation model. Thus, we offer it as one part of the implicit cost. TRC_n and l represent transaction cost for the government in year n and the project life span, respectively. In reality, calculating transaction costs is not an easy task. This paper recommends a simplified calculation method, which involves taking a certain proportion of project costs based on past project experiences and negotiation efficiency between both parties. Furthermore, transaction costs are another part of the implicit costs, effective throughout the entire project lifecycle. RC_n represents the regulation cost for the government in year n. Based on real-world project experience, a specific proportion of annual operating costs was employed to calculate regulatory costs in this study. The above methods for calculating transaction and regulatory costs are also a practical method for calculating transaction costs when evaluating PPP projects in practice in China. Although these methods may not provide highly accurate results, they can still be effectively utilized in decision-making due to its practicality and ease of implementation.

In this research, the social value was classified as implicit value earned by the government as an agent of the end users. This article applied the Cobb–Douglas (CD) function based on micro-economic fundamentals to simulate the social value calculation. The positive externalities of APO projects can be categorized into two aspects: Firstly, these projects contribute to the promotion of the regional economy. For example, road projects play a vital role in reducing transportation time and stimulating economic development (Ivanova & Masarova, 2013). Secondly, APO projects also have a positive impact on the regional environment. For instance, park projects contribute to environmental preservation and enhance the quality of living conditions (Yuan et al., 2020). The social value of these positive externalities is internalized by this model, which involves a highly intricate estimation process. Previous studies have utilized the contingent valuation method (CVM), which is based on willingness to pay (WTP), to evaluate the environmental externalities associated with green electricity, as an illustrative example (Oerlemans et al., 2016). The externalities arising from urban development, such as the increase in land rent in the Central Business District (CBD), can be quantified using the bid-rent model (Adhikari, 2016). However, applying these methods to APO projects that encompass various types of infrastructure proves challenging due to the complex nature of these approaches. The CD function used in our model considers the compromise between model usability and intricacy. Considering the general form of CD function, $Y = AK^{\alpha}L^{\beta}$, where Y means total production, K means capital input, L means labor, A means total factor productivity, and α and β are the output elasticities of capital and labor, respectively (Brown, 2017). The logic underlying this input-based output function model can be analogized to APO projects. Specifically, the investment in construction costs determines the project scope, serving as a capital input for generating social value. Similarly, the project's operating costs can also be regarded as an input factor. The coefficients of the production function are determined by the level of management and effort exerted by investors. The rationales for employing the CD function are:

1. The methods for calculating social value in the literature have a relatively narrow scope of application. For instance, the method based on passenger time savings is only applicable to cable car projects, and currently there is no single method applicable to most projects (Liou et al., 2011).
2. In micro-economics, the CD function is frequently employed to assess diverse input-output relationships (Liu et al., 2021). Its strong interpretability enables its parameters to bear distinct economic implications in diverse research, thus offering a persuasive example for the selection of this study (Zhao et al., 2021).
3. For PPP projects, the generation of social value mainly stems from the availability of built project facilities. The availability of facilities provides basic social value, while the careful maintenance of social capital can provide an additional markup on this basic value. The process of generating social value reflects an input-output relationship, and when using the CD function to roughly estimate social value, the meanings of each parameter can be reasonably explained.

In an APO PPP project, this paper sets the social value to be calculated as the output of the CD function (i.e., Y). Forming an infrastructure entity depends on capital investment (i.e., construction costs), which can be considered capital input (i.e., K). Moreover, the project company provides the service enjoyed by the end users during the long-term operation. The project company inputs operating costs to procure materials and employ management and labor teams. We adopted the operation cost to approximately substitute the labor input (i.e., L). Adopting the CD function to measure the correlation between social value and project investment may not be precise, but it is enough for practical use.

4.1.2. Valuation model for investors

According to the above reasoning process for Figure 3 of valuation logic for the investors' value, we can define:

$$V_I = ER_I + IR_I - EC_I - IC_I, \tag{6}$$

where V_I means value to investors of a PPP Project, ER_I, IR_I, EC_I, IC_I represent investors' discounted explicit return, implicit return, explicit cost, and implicit cost, respectively. Explicit return and cost mainly indicate the net present value belonging to investors, which scholars and practitioners usually refer to as sources of financial benefit for investors derived from a PPP project. Implicit return and cost largely encapsulate a wide range of real-world issues, but these are typically ignored by scholars when developing financing models:

$$ER_I = \sum_{n=1+t_1}^{t_1+t_2} \frac{CC \times PoCI \times (1-PoGI) \times r_\alpha \times (1+r_\alpha)^{t_2}}{\left[(1+r_\alpha)^{t_2}-1\right](1+i_I)^n} + \sum_{n=1+t_1}^{t_1+t_2} \frac{OC_n \times (1+r_m)}{(1+i_I)^n}, \tag{7}$$

where i_I is the discount rate for investors.

$$IR_I = \sum_{n=1}^{t_1} \frac{CC_n \times r_{bc}}{(1+i_I)^n}. \tag{8}$$

Implicit revenue mainly indicates investors earned profits from organizing construction. Construction profit is the first-order demand for many investors in PPP projects, especially those transformed from contractors focusing on traditional civil engineering and construction:

$$EC_I = \sum_{n=1}^{t_1} \frac{CC_n \times PoCI \times (1-PoGI)}{(1+i_I)^n} + \sum_{n=1+t_1}^{t_1+t_2} \frac{OC_n}{(1+i_I)^n} + \sum_{n=1+t_1}^{t_1+t_2} \frac{TAX_n}{(1+i_I)^n}; \tag{9}$$

$$IC_S = \sum_{n=1}^{t_1+t_2} \frac{\sum_k RCI_n^{(k)}}{(1+i_I)^n}. \tag{10}$$

Implicit cost for investors, of course, does not only include risk costs; for instance, internal transaction costs and managing costs not being booked in the ledger are also implicit. Nevertheless, those costs are usually generated on the company aspect and thus not easily be measured for a specific project. Risk costs are overwhelming in implicit costs. Some parts of other implicit costs are included in the costs of specific risks. Therefore, risk costs could be adopted to represent the implicit costs of investors in PPP projects.

4.2. Finite-horizon bargaining game model

For this study's objectives, we define:

$$V_P = V_G + V_I, \tag{11}$$

where V_P means value for partnership between the government and investors in a PPP Project, which will be negotiated and shared by both of them. V_P was adopted as the bargaining surplus. To calculate V_P, the project's total value, a uniform discount rate should be used to discount cash flows. The most appropriate discount rate would be Weighted Average Cost of Capital (WACC), but at the decision-making stage, the investor's return on capital has not been determined, so it is impossible to calculate an accurate WACC. Thus, a basic discount rate can be used. In the decision-making stage, we assumed that r_c represents the basic discount rate both partners agree.

Then, the following equation to calculate V_P is obtained:

$$V_P = \lambda CC^a OC^b - \left(\sum_{n=1+t_1}^{t_1+t_\beta} \frac{CC \times (1-PoCI) \times r_\beta \times (1+r_\beta)^{t_\beta}}{\left[(1+r_\beta)^{t_\beta} - 1\right](1+r_c)^n} - \sum_{n=1}^{t_1} \frac{CC_n (1-PoCI)}{(1+r_c)^n} \right) - \left(\sum_{n=1+t_1}^{l} \frac{RC_n}{(1+r_c)^n} + \sum_{n=1}^{l} \frac{TRC_n}{(1+r_c)^n} \right). \tag{12}$$

The equation of V_P was deconstructed into three parts (i.e., social value minus profit of lenders and minus the sum of regulation cost and transaction cost). Even for projects initiated by the government, in practice, investors often participate in projects at an early stage for the purpose of seeking potential investment opportunities. The government actually welcomes this, as it often means sufficient competition in favor of VFM (Ministry of Finance, 2015b). Therefore, although the first proposal of a PPP project is usually the government sector, the negotiating and bargaining process can also be initiated by investors who participated in the project early. The offer may be a biding intention instead of a formal quotation. Table 2 and Table 3 show the bargaining process initiating by the government and investors, respectively.

Table 2. Government initiates the bargaining

Stage	Proposer	V_G	V_I
1	Government	$V_P - \delta_I(V_P - \delta_G V_P)$	$\delta_I(V_P - \delta_G V_P)$
2	Investors	$\delta_G V_P$	$V_P - \delta_G V_P$
3	Government	V_P	0

Table 3. Investors initiate the bargaining

Stage	Proposer	V_G	V_I
1	Investors	$\delta_G(V_P - \delta_I V_P)$	$V_P - \delta_G(V_P - \delta_I V_P)$
2	Government	$V_P - \delta_I V_P$	$\delta_I V_P$
3	Investors	0	V_P

We define p_G and p_I as the probability of the final proposer being the government and the investors, respectively, then, we have:

$$p_G + p_I = 1. \tag{13}$$

Then, by three-stage bargaining, we have:

$$V_G^* = p_G V_G^G + p_I V_G^I; \tag{14}$$

$$V_I^* = p_G V_I^G + p_I V_I^I, \tag{15}$$

where $V_G{}^G$ and $V_G{}^I$ represent optimal government shared value when the government and investors are the final proposers, respectively; $V_I{}^G$ and $V_I{}^I$ represent optimal investors' shared value when the government and investors are the final proposers, respectively. Next to the $V_G{}^*$ and $V_I{}^*$ were obtained by the bargaining model, we can set the feasible region of (r_α, r_m, t_2) according to the backgrounds of actual projects. The feasible region is shown as Eqn (16):

$$\Phi = \left[(r_\alpha, r_m, t_2) \middle| r_c \le r_\alpha \le r_{\alpha\max}; r_c \le r_m \le r_{m\max}; t_\beta \le t_2 \le l \right]. \tag{16}$$

Then, setting $V_G(r_\alpha, r_m, t_2) = V_G{}^*$, we obtained the solution set, as Eqn (17) shows, by backward calculation approach:

$$\Psi = [(r_\alpha, r_m, t_2) \in \Phi \,|\, V_G(r_\alpha, r_m, t_2) = V_G^*]. \tag{17}$$

4.3. Determining concessionary items by MODM model

In order to accurately determine optimal concessionary items, and in considering parties differing attitudes towards risk, we established an MODM model based on the assumption that both partners have different discounted rates. The feasible region of the MODM model was given in advance based on the solution set by the bargaining model. The MODM model is shown below:

$$\text{Max}\left[V_G^{i_G}(r_\alpha, r_m, t_2), V_I^{i_I}(r_\alpha, r_m, t_2) \right] \tag{18}$$

$$s.t \begin{cases} (r_\alpha, r_m, t_2) \in \Psi \\ V_G^{i_G}(r_\alpha, r_m, t_2) > 0 \\ V_I^{i_I}(r_\alpha, r_m, t_2) > 0, \end{cases}$$

where $V_G^{i_G}$ and $V_I^{i_I}$ represent V_G and V_I calculated by i_G and i_I, respectively. Then, solving the MODM problem, we can obtain the optimal solution $(r_\alpha^*, r_m^*, t_2^*)$.

5. Model application

5.1. Example project background and input parameters

A real project case applied to demonstrate the capabilities of the proposed model in determining the three concessionary items (i.e., ROIC, ROOM, and concession period) is presented in this section. The case PPP project in Si-

Table 4. Input parameters of the value model

Input parameters	Brief	Value
CC	Total investment of construction	￥1219.28 million
$PoCI$	Proportion of capital investment	20%
$PoGI$	Proportion of capital government invested	10%
t_1	Construction period	3 years
l	Project lifespan	40 years
t_β	Financing repayment period	12 years
r_β	Financing interest rate	7.3%
OC_1	Operation cost in first operation year	￥1.74 million
OC	Total operation cost during the project's lifespan	￥38.18 million
r_{inf}	Inflation coefficient	3%
i_S	Discount rate for investors	10%
i_G	Discount rate for the government	6%
r_{bc}	Profit margin of construction	16.1%
TAX_{rate}	Effective tax bearing rate	3.45%
RC_{rate}	Regulation cost rate	5%
TRC_{rate}	Transaction cost rate	3%
RCS_{total}	Total transferable risk $\left(\sum_n \sum_k RCS_n^{(k)}\right)$	￥159.71 million
λ[1]	Coefficient of social value	1.5
a	Output elasticity of construction investments	0.4
b	Output elasticity of operation investments	0.6
r_c	Basic discount rate mutually agreed	5%

Note: Please see the Appendix 1 to the calculation process explanation for the coefficient of social value.

chuan Province, China, comprises three municipal roads, one bridge, and three urban parks. This project adopts the Build-Operation-Transfer (BOT) delivery method. The facilities, once completed, will be freely accessible by the public throughout the concession period. Input parameters of the value model, and the bargaining model are provided in Table 4 and Table 5, respectively.

5.2. Nash Equilibrium and optimal concessionary items

According to Eqns (15) and (16), we have:

$V_G^* = 56.35$million;

$V_I^* = 50.98$million.

As Figure 5 shows, according to the backgrounds of the example project, we set:

$$\Phi = \left[\left(r_\alpha, r_m, t_2\right) \middle| 5\% \le r_\alpha \le 12\%;\ 5\% \le r_m \le 24\%;\ 10 \le t_2 \le 30\right].$$

Then, setting $V_G\left(r_\alpha, r_m, t_2\right) = V_G^* = 56.35$, we obtained the solution set, i.e., set Ψ, by backward calculation approach according to Eqn (18), as Figure 6 shows. Appendix 2 shows the detailed solution process of Figure 6. By solving the optimization problem showing as Eqn (19), the optimal concessionary items group was obtained $\left(r_\alpha^*, r_m^*, t_2^*\right) = \left(0.087, 0.056, 12\right)$.

Table 5. Input parameters of the bargaining model

Input parameters	Value	Input parameters	Value
δ_I	0.8	p_I[1]	0.5
δ_G	0.85	p_G	0.5

Note: The value of p_I is a calculation assumption referring to a previous study (Bayat et al., 2020).

5.3. Results analysis

In the real case, the final bid-winning price reported for ROIC, ROOM, and concession period, were 8.4%, 8%, and 13, respectively. In terms of ROIC and concession period, the optimal solution came close to the actual values, indicating that the model is applicable and practical. This model can be used as a reference for setting return levels at the decision stage of a PPP project while also guiding decisions regarding the controlled bidding price. Additionally, the calculated ROOM result is lower than the actual transaction result. Overall, real transaction results indicate that the government has greater bargaining power than the model assumes. The government may tend to give a lower ROIC while extending the concession period because this can reduce the government's payment pressure during the operation period. Higher ROOM can be taken as compensation that accounts for a very low proportion of the total income for investors.

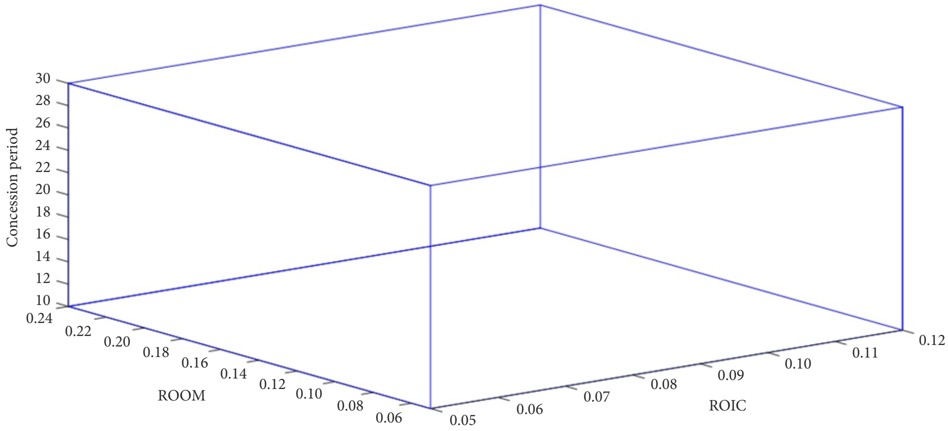


Figure 5. Feasible region

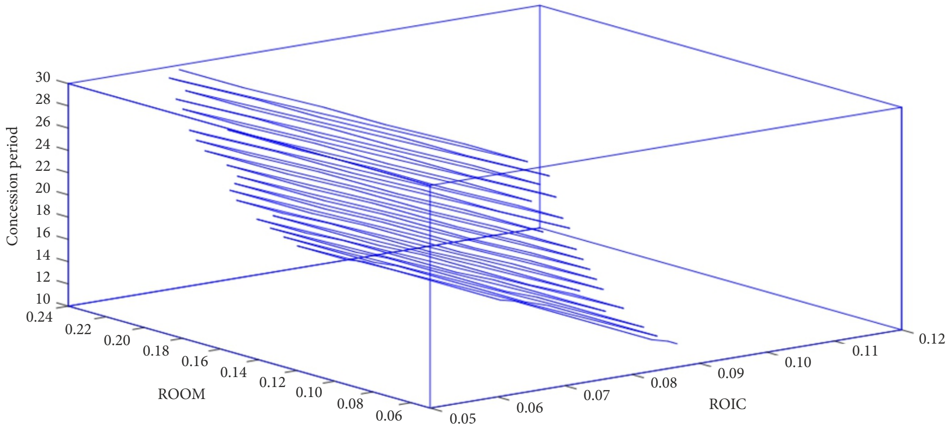


Figure 6. Solution set

In the light of previous results, an in-depth sensitivity analysis was conducted. Firstly, construction benefit was analyzed in regards to the vital role played on investors' return. According to Eqn (13), the total project value to be shared and V_G^* do not change with the change in construction profits. However, the solution set and optimal concessionary items group where variable. The sensitivity analysis, shown in Figure 7, was conducted by examining scenarios in which both results varied by a 5% change in the construction benefit. The solution set contains roughly the same number of solutions and translates from the original site to another site when the construction profit decreases. The situation is similar when the construction benefit increases by 5%, 10%, or 15%. The number of solutions is significantly reduced, and extended concession periods are not included in solution sets when the construction profit increases by 20% and 25%. The feasibility constraint may explain this. In other words, the result indicates a relatively narrow feasible solution set. From the perspective of optimal concession items, there are two null groups when the construction benefit decreases by 20% and 25% (see Table 6). The main reason is that a low construction profit makes $V_I^{i_I}$ negative, leading to an empty feasible region of the optimization problem. Moreover, the government can accept paying higher construction benefits because of its lower discount rate than investors. When the optimal concession period is equal, the change of ROIC decreases monotonically with increasing construction profits. Nevertheless, ROOM changes are diverse and irregular, which can be explained by the operation return's low share of cash inflow. Overall, it is apparent that the level of construction profit can significantly affect the feasible and optimal concession items set.

Secondly, a sensitivity analysis was conducted on the basic discount rate, as it has a noticeable impact on the calculation of V_P. When the basic discount rate fluctuates within ±25% of the original value, the changes in the solution set and the optimal concessionary items group are illustrated in Figure 8 and Table 7, respectively. The solution set shifts from the original location to another site as the basic discount rate changes. The model provides at least one feasible concession item group for the project, even if it is not optimal. Regarding the optimal concession item group under different basic discount rates, optimal groups exist in all cases except when the basic discount rate decreases by 15%. The optimal concession period is not significantly influenced by variations in the basic discount rate. Among the optimal concession item groups where the concession period is equal, a monotonic increase in ROIC is observed with higher basic discount rate. This result is derived from the underlying cash flow structure of the project and the methods employed in the model.

Table 6. Sensitivity analysis of optimal solution for the construction benefit

Construction benefit	ROIC	ROOM	Concession period
–5%	9.5%	7.2%	12
–10%	10.3%	7.8%	12
–15%	11.1%	7.3%	12
–20%	–	–	–
–25%	–	–	–
16.1% (origin)	8.7%	5.6%	12
+5%	7.8%	10.4%	12
+10%	12%	20.5%	11
+15%	11.3%	8.7%	11
+20%	10.4%	12.2%	11
+25%	9.6%	6.7%	11

Table 7. Sensitivity analysis of optimal solution for the risk allocation

Basic discount rate	ROIC	ROOM	Concession period
–5%	8.1%	7.2%	12
–10%	7.5%	8.9%	12
–15%	–	–	–
–20%	11.9%	7.6%	11
v25%	11.4%	10.5%	11
5% (origin)	8.7%	5.6%	12
+5%	9.2%	11.8%	12
+10%	9.8%	10.4%	12
+15%	10.4%	8.9%	12
+20%	11.0%	7.5%	12
+25%	11.6%	6.1%	12

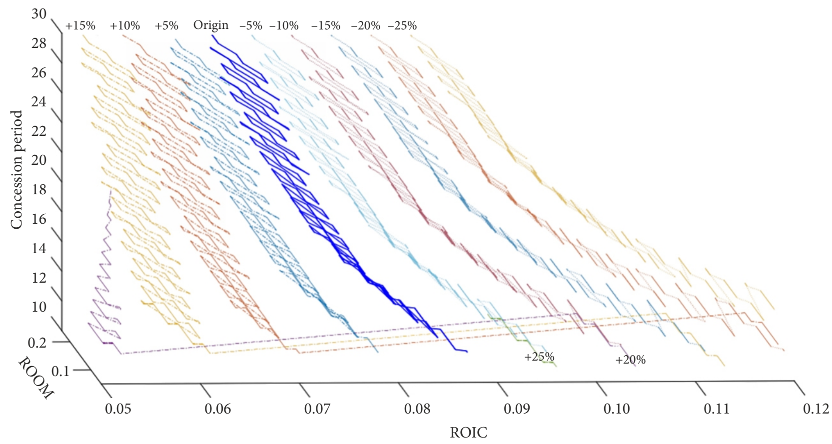


Figure 7. Sensitivity analysis of solution set for the construction benefit

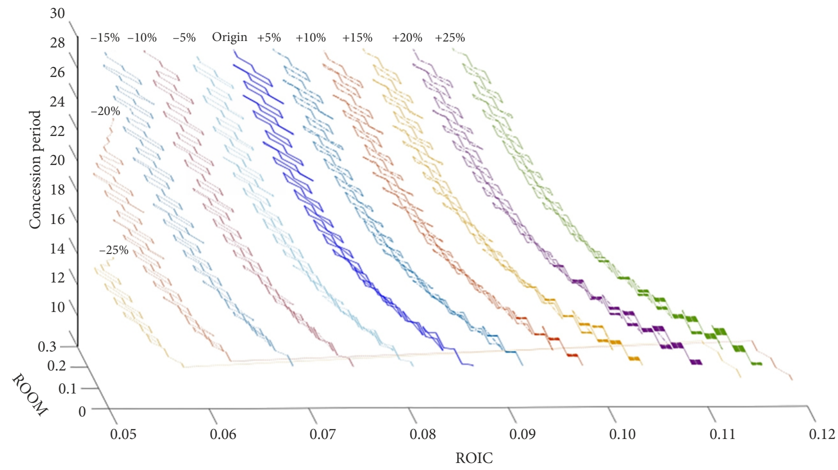


Figure 8. Sensitivity analysis of solution set for the basic discount rate

In the model developed within this study, the interests of both the government and investors are evaluated using net value, which represents the returns minus costs. Additionally, similar to the sensitivity analysis of construction benefits, the changes in ROOM are diverse and irregular.

Secondly, the proposed model should consider risk allocation as a critical success factor of PPPs. We investigated changes in the solution set and optimal concession items group by setting the ratio of TR to RR from 9:1 to 1:9. The actual ratio in the example project is 8.2:1.8. As shown in Figure 9, when the ratios are lower than 7:3, the solution sets do not contain concession periods higher than 12 years. This result can be explained in that V_G is negative until the ratio of TR to RR drops lower than 7:3, with the government transferring fewer and fewer risks to investors. In other words, according Eqns (2), (6) and (13), the risk allocation ratio affects V_G by influencing VFM, which has been decreased with the risk allocation ratio

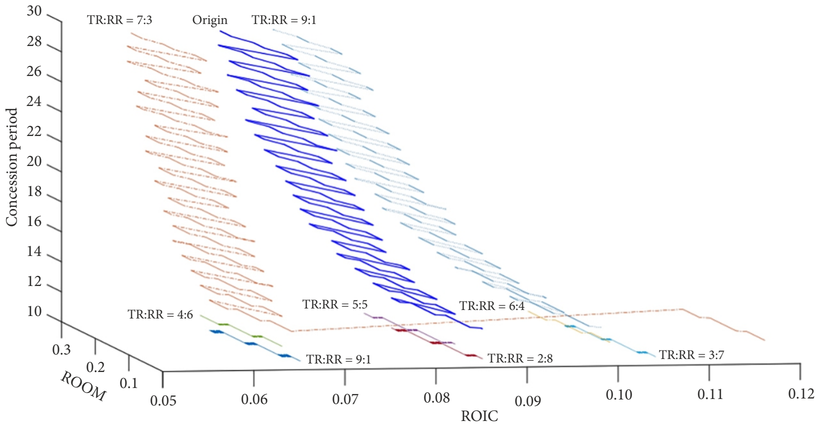


Figure 9. Sensitivity analysis of solution set for the risk allocation

becoming lower and lower. From the perspective of the optimal concession items group, the optimal concession period is relatively stable at 10–12, followed by optimal ROIC at 6.5%–11.8%, with ROOM fluctuating the most at 5.2%–15.1% (see Table 8). This result shows that the optimal concession period is less sensitive to changes in the risk allocation ratio. Various risk allocation ratios can significantly change the optimal ROIC and ROOM.

Finally, the social value should be analyzed, with V_P changed accordingly. At the same time, δ_I and δ_G will differ because of the change of V_P. δ_I and δ_G reflect the degree of patience the government and investors have in the game. If V_P increases or decreases, both parties may exhibit more or less patience for sharing V_P throughout the game. As a result, quantitative sensitivity analysis to the impact of changes in social value is complex, but qualitative analysis can still be conducted. Once the scale and scope of the project are determined, the social value will be an approximately exogenous parameter that will not change significantly. However, the efforts of investors in the operation stage and external environmental factors' changes may still cause changes in social value. This effect will manifestly change the solution sets because V_G^* will vary significantly following Eqn (13).

Table 8. Sensitivity analysis of optimal solution for the risk allocation

TR:RR	ROIC	ROOM	Concession period
9:1	10%	5.2%	12
8.2:1.8 (origin)	8.7%	5.6%	12
7:3	11.8%	10.5%	11
6:4	10.1%	10.7%	11
5:5	8.4%	6.2%	11
4:6	6.5%	11.4%	11
3:7	10.5%	7.4%	10
2:8	8.5%	14.4%	10
1:9	6.5%	15.1%	10

6. Discussion

Compared to existing literature, the first contribution of this research lies in proposing a more comprehensive and holistic framework by which to evaluate values gained by the government and investors in PPP projects. In previous studies, the modeling of returns earned by investors, were typically based on DCF theory and discounted future cash flow, but ignored the construction profit that investors obtained in terms of the construction process (Alghamdi et al., 2022; Jin et al., 2021). In practice, especially in China, tendering of PPP projects often integrates construction and operations (Ministry of Finance, 2016; National People's Congress, 2017). The proportion of construction profits contributing to an investors' total return is very high, especially in APO projects. In this study, the valuation model for investors more accurately includes both implicit and explicit returns and costs. Sensitivity analysis also reveals that the construction benefit level can significantly impact the optimal concession items. On the other hand, social welfare, which is an essential value item for the government, though overlooked in previous studies, has also been included in the valuation framework of this study (Repolho et al., 2016; Sun & Zhang, 2015; Xiong et al., 2022). Going a step further, this article pioneers the introduction of quantitative VFM into the governmental valuation and concessionary items determination.

This study develops a novel approach by incorporating the positive externalities of infrastructure APO PPP projects into the model through the internalization of social value as part of the government's implicit returns. Research has indicated that the assessment of externalities should be considered a crucial element in the phased evaluation of PPP projects (Liu et al., 2022). PPP projects exhibit both positive and negative externalities, and private capital often leverages economies of scale to enhance positive externalities, thereby generating a favorable impact on the regional economy and society (Meduri Surya & Annamalai Thillai, 2013). However, little research has been conducted on internalizing the value of positive externalities to evaluate APO projects, despite the government's recognition of their significance when initiating such projects (Jin & Liu, 2023). In the fields of environmental economics and real estate economics, externalities are typically measured using methods like the CVM and bid-rent approaches, respectively (Adhikari, 2016; Oerlemans et al., 2016). However, due to the diverse nature of infrastructure types encompassed by APO projects, there is currently no standardized measurement method to calculate the social value (positive externalities) of these projects. The CD function-based approach employed in this study offers an approximate and simplified method for measuring social value. While this approach can be practically applied, further refinements and enhancements are warranted.

The other contribution of this paper is in proposing a methodology for determining essential concession items for APO PPP projects specifically. The methodology differs from existing research, which focuses on PPP projects whose return mechanism is revenue-based (UCO) or mixed (VGF) (Bayat et al., 2019; Jin et al., 2019; Xu et al., 2017). Results reflect closely the actual transaction situation, providing confidence that the proposed framework reflects the particularity of APO projects. That is, government is demonstrated to have greater bargaining power, with operation returns accounting for a lower proportion of the total income. A similar paper is that of Bayat et al., who adopted a seven-stage finite alternative bargaining model to allocate the NPV during the life span of PPP projects between government and a union of investors and lenders (Bayat et al., 2020). However, they concluded that all the government extracts from a project is cash flow, which is not the case. In APO PPP projects, the government does not obtain cash inflows. Instead, their benefits lie VFM and social values, which are not presented in the form of cash flow. The study does not fit APO projects well, and this paper improves on that.

Moreover, compared with other studies that give only an interval or a specific value, a feasible interval and an optimal concession items group can be determined by this methodology (Bayat et al., 2020; Khanzadi et al., 2012). Through a backward calculation of the bargaining result, an indifferent feasible interval under the same discount rate agreed by both parties can be obtained. Furthermore, based on the respective discount rates of both parties, an MODM method was utilized to determine the optimal concession items. Existing studies adopting the MODM method in this area usually integrate the simulation method since they need to analyze the uncertainty of user charges (Iyer & Sagheer, 2012; Sun et al., 2019; Sun & Zhang, 2015; Xu et al., 2017). However, this paper extends the application of MODM, in which the feasible region is given in advance, based on the bargaining model.

After considering the fundamental distinction of APO PPP projects, i.e., the government bears demand risk, the proposed model in this paper effectively captures this risk allocation through the determination of decision variables and the design process of the proposed model. Firstly, the ROIC is a contract clause in APO PPP projects in China, under which the government pays returns to investors. The return on capital for investors is solely determined by this clause and is not related to the magnitude of demand. The ROOM clause determines the operation and maintenance return for investors, which only depends on the actual operation and maintenance costs and performance evaluation, and is also not related to demand. Secondly, the design process of the proposed model involves first allocating project value, and then determining the concessionary items. Considering that the demand risk is borne by the government, i.e., included in the government's retained risk, the value of the retained risk cost has been offset (see Eqn (4)) in the calculation of VFM (the government's explicit return minus cost). This indicates that the proposed model reflects this particular feature of demand risk allocation. Furthermore, the implications and applicability of the model is summarized, as follows:

1. The proposed framework can be adopted in APO PPP projects with the same price structure in the decision-making stage. In practice, this price structure taking a group of ROIC, ROOM, and concession periods as the core transaction condition has been applied across thousands of PPP projects. Determining these metrics provides a benchmark price for APO PPP projects for both partners, The bargaining power and value reduction rate of both partners, predicted based on the decision-making stage, may undergo dynamic changes in subsequent procurement stages. If investors require a higher ROIC based on their own calculations, the government can adjust the ROOM and concession period, such as reducing the ROOM or shortening the concession period, to rebalance the value allocation. The new group of concessionary items may no longer be the optimal solution under the original conditions, but it may be the optimal solution under the new situation.
2. For APO PPP projects involving competitive bidding, the proposed framework can be employed by the government to establish a tendering control price for project tendering. When a project is initiated by an investor, it means that at least one investor has agreed to a specific price, which can serve as a control price for tendering. Other competitors can still bid. However, it is generally not necessary to select the investor with the lowest bid as too low a bid may lead to the potential risk of project failure. The evaluation of bids may be based on best value or hybrid methods. Additionally, the tendering process is also a new game that can be simulated using the proposed model, but this simulation may not be entirely suitable due to legal constraints in the tendering process. The proposed model is more suitable for the decision-making stage rather than the procurement (tendering) stage. Nevertheless, for APO PPP projects procured through competitive negotiation, the proposed framework can be used for both simulation in the decision-making stage and negotiation in the procurement process.

3. For government, if the availability payment serves as the primary source of return in a project, two tasks, investigating the level of construction profit of potential investors and planning a reasonable risk allocation scheme, should be done in advance, in accordance with the sensitivity analysis of 5.3 section. For investors, considering the bargaining power of both partners and evaluating social benefits the government gained helps them make a strategic go/no-go and negotiation decision based on their specific circumstances and strategic objectives.

7. Conclusions

This study proposed a VFM and social value integrated framework to determine key concessionary items for APO PPP projects. The DCF method was used to establish valuation models for the government and investors. A three-stage bargaining game was adopted to allocate the APO PPP projects' value. By solving the game model, a solution set was obtained to be a feasible region under the MODM method, in which optimal concessionary items were determined. Comparing calculated results with the actual case bid price, the feasibility and applicability of the framework proposed in this article was verified. Additionally, the project construction benefit was shown to significantly affect feasible and optimal concession items. The optimal concession period is less sensitive to changes in the risk allocation ratio. Various risk allocation ratios can significantly change the optimal ROIC and ROOM. Once the scale and scope of the project are determined, the social value created by the project will only be changed by investors striving for technical innovation in the operation stage, or as a result of drastic changes in the external environment. The contribution of this study is twofold: it proposes a more comprehensive and holistic framework for evaluating values obtained by the government and by investors in APO PPP projects, and provides a methodology for determining a feasible interval and an optimal concession items group, tailored to APO PPP projects.

This study was limited to validating the model through numerical simulation using only one real-world case. Future research can explore additional theoretical methods to validate the proposed model. The current research presents a comprehensive model that generally provides meaningful insights into the division of benefits and costs. However, there is a need for further improvement in the calculation details of certain benefits and costs. For example, the current model calculates the cost of transferring risks based on simplified real-world calculations. Future research can focus on developing more accurate and comprehensive methods to calculate these specific benefits and costs, thereby enhancing the practicality and applicability of the model.

Notations

Abbreviation/symbol	Full name/meaning
PPP	Public-private Partnerships
APO	Availability Payment Only
VGF	Viability Gap Funding
UCO	User Charge Only
NPV	Net present value
VFM	Value-for-money
DCF	Discounted cash flow
MODM	Multi-objectives decision-making
PSC	Public sector comparator
PSB	Private shadow bid
RPSC	Raw PSC
CN	Competitive neutrality
TR	Transferred risk
RR	Retained risk
GCP	Governmental construction payment
CASP	Capital annual service payment
NCASP	Non-capital annual service payment
ROIC	Return on invested capital
ROOM	Return on operation and maintenance
MRG	Minimum Revenue Guarantee
CD	Cobb-Douglas
CC_n	Construction cost in operation year n
$PoCI$	Proportion of capital investment
$PoGI$	Proportion of capital government invested
t_1	Construction period
l	Project lifespan
t_β	Financing repayment period
r_β	Financing interest rate
OC_n	Operation cost in operation year n
r_{inf}	Inflation coefficient
i_S	Discount rate for investors
i_G	Discount rate for the government
r_{bc}	Profit margin of construction
TAX_{rate}	Effective tax bearing rate
RC_{rate}	Regulation cost rate
TRC_{total}	Transaction cost rate
RCS_{total}	Total transferable risk $\left(\sum_n \sum_k RCS_n^{(k)}\right)$
λ	Coefficient of social value
a	Output elasticity of construction investments
b	Output elasticity of operation investments
r_c	Basic discount rate mutually agreed

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Author contributions

YG and CC conceived the study and were responsible for the design and development of the data analysis. YG, XL and IM were responsible for data collection and analysis. YG and CC were responsible for data interpretation. YG wrote the first draft of the article.

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APPENDIX

The calculation process explanation for the coefficient of social value (Appendix 1) and detailed solution process of Figure 6 (Appendix 2) can be found in the Supplementary materials.