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CONCESSION MODEL FOR FAIR DISTRIBUTION OF BENEFITS AND RISKS IN BUILD-OPERATE-TRANSFER ROAD PROJECTS

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Abstract. A fair distribution of benefits and risks is not only one of the key factors in deciding concession period but also an important prerequisite for good cooperation between the government and the private sector in a Build-Operate-Transfer (BOT) road project. Considering the psychological characteristic of decision makers' fairness preference, this study innovatively introduces the inequity aversion theory into the concession model, which provides a novel perspective to investigate the distribution of benefits and risks. In the improved model, the decision makers' investment utility involves their economic benefits as well as their disutility due to inequity. Furthermore, the equilibrium principle of benefits and risks in this model has changed to minimize the gap between the investment utility-risk ratios of the government and the private sector. Based on Monte Carlo simulation, this study verifies the application of the model to a BOT road project in China. The results show that the concession period with fairness preference can effectively narrow the gap between the investment utility-risk ratios of the government and the private sector, thus guaranteeing the fair distribution of benefits and risks in the BOT road project.

Keywords: concession period, fairness preferences, inequity aversion theory, investment utility-risk ratio, Monte Carlo simulation.

Introduction

The Build-Operate-Transfer (BOT) scheme has been used effectively to alleviate the government's financial burden by attracting the private sector to participate in public facilities (Shahrara, ÃElik, & Gandomi, 2017). As an important content of BOT contract, concession period defines the time span in which the private sector has the right to commercially operate the BOT project before it is transferred back to the government (Y. Zhang, Feng, & S. Zhang, 2018; Shen, Bao, Wu, & Lu, 2007). During the concession period, the private sector receives the operating income and undertakes the risks of construction and operation. If the concession period is longer than a fair value, the private sector can receive extra benefits, while the government will think that the public interests is damaged (Shen, H. Li, & Q. Li, 2002). In contrast, if the concession period is shorter than a fair value, the government will operate the BOT road for a longer time, while the private sector will bear the losses and eventually stop cooperating with the government (Yu & Lam, 2013). Therefore, an equitable distribution of the two parties' benefits and risks is crucial in deciding a fair concession period (Feng, Wang, Li, Chunlin, & Xiong, 2018).

In deciding the fair concession period, some studies assume that the players are rational and fully concerned about their own benefits. Among existing studies, game models are the most common approaches to balance the net present value (NPV) and risks of two sides, such as the incomplete information bargaining model (Bao, Peng, Ablanedo-Rosas, & Gao, 2015), Stackelberg game model (Wu, Jing, & Wei, 2011), and Nash bargaining game model (Zhang, Xu, & Liu, 2011). Other studies establish a win-win model, which means that fair concession period is calculated to maximize the NPV of two sides (Shen et al., 2002; Zhang & AbouRizk, 2006; Ng, Xie, Cheung, & Jefferies, 2007a) and to allow for a fair risk sharing (Carbonara, Costantino, & Pellegrino, 2014). It is easy to find that most models in the literature consider economic benefits of a project as an important factor for determining the fair concession period. Besides NPV, the internal rate of return (IRR) (Ng et al., 2007a) as well as the least-present-value of revenue (LPVR) (Engel, Fischer, & Galetovic, 2001) are considered as the evaluation criteria of economic benefits.

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However, psychology and behavioral science studies found that people in real life were bounded rationality (Sen, 1995). Only considering the economic benefits in deciding the concession period will result in ignoring the effects of individual irrational behavior under risks (Wibowo & Alfen, 2013), such as the unfairness aversion behavior (Fehr & Schmidt, 1999). Therefore, decision makers are concerned about the benefits of others and whether the distribution of material interests or risks is fair-minded (Samuelson, 1993; Tang & Wang, 2013). For example, in determining the concession period, the private sector has a fairness preference, which means it cares about whether the concession period has a reasonable value and if the government acquires excess benefits (Wang & Liu, 2015). Once the private sector feels that the concession period is unfair, it will take many measures to improve the distribution of fairness, even at the cost of its own benefits (Fehr & Schmidt, 1999, 2006), such as slacking or exerting minimal effort to punish an unfair result (Wang, Cui, & Liu, 2018). The inequity aversion theory, proposed by Fehr and Schmidt (1999) reveal the influence of the fairness preference on investment utility. Today, the inequity aversion theory has become the most common research method of studying fair benefit distribution (Luebker, 2014).

By introducing the inequity aversion theory, the government and the private sector will follow the principle of bounded rationality to decide the concession period. First, the government and the private sector not only focus on their own benefits, but also compare them with those of others (Fehr & Schmidt, 1999). Second, investment benefits are replaced by investment utility, which includes economic benefits and the disutility brought about by the sense of inequity (Fehr & Schmidt, 1999, 2006). Third, maximizing the economic benefits of both sides will be transformed into minimizing the gap between the investment utility-risk ratios of the government and the private sector. In addition, this study also measures the two decision makers' investment risks from the perspective of their respective funding sources. To improve the fair distribution of benefits and risks in a BOT project, this study aims to develop a fair decision model to calculate the concession period.

This paper is organized as follows. Section 1 reviews the research foundation for determining the fair concession period. Section 2 thoroughly describes the decision-making model of concession period based on inequity aversion theory. Section 3 presents a case study of a BOT highway project in China to verify the application of the Monte Carlo simulation model. Section 4 provides theoretical and practical implications, and the last section concludes.

1. Literature review

1.1. Risks and uncertainties affecting decision making

Many risks influence the calculation of the concession period, and thus risks and uncertainties have been widely researched. Tiong (1990) expresses that BOT road projects have a high level of risks due to high initial capital, long construction cycle, and long payback period. Therefore, the government and the private sector must be fully aware of all possible risks involved in BOT projects. Li (2003) believes that risks can be classified into three levels: macro-level risks; meso-level risks, and micro-level risks. Ng and Loosemore (2007) divide risks into technical risks, construction risks, operating risks, revenue risks, and financial risks. More recently, Hanaoka and Palapus (2012) have considered the effect of risks on uncertain concession items in project evaluation to calculate the reasonable concession period. Generally, previous studies have investigated risks and concession period from different perspectives, such as construction time, construction cost, traffic volume, and maintenance cost (Cruz & Marques, 2013; Saha & Ksaibati, 2015). Lv, Ye, Liu, Shen, and Wang (2014) consider the uncertainty of future traffic demands in determining the optimal concession period. Ng et al. (2007a) regard cost, operation revenue, and income as uncertain parameters.

Risks should be considered and quantified and when deciding the appropriate length of a concession period (Bing, Akintoye, Edwards, & Hardcastle, 2005). Monte Carlo simulations have been used in calculating the concession period (Ng et al., 2007a; Shen & Wu, 2005; Zhang & AbouRizk, 2006), where the focus of the simulations is to establish the distribution function of uncertain variables (Liou & Huang, 2008; Wang, Chang, & El-Sheikh, 2012). Considering the relative risks and uncertainties, this study proposes a decision model to determine a proper concession period using Monte Carlo simulation.

1.2. Fairness in BOT project

Using a case study approach, Jamali (2004) indicates that "fairness" is one of the basic foundational underpinnings of successful BOTs. This has raised concerns on the related issues of fairness in the supposed partnership between the government and the private sector. For example, Villamejor-Mendoza (2011) defines fairness in Build-Operate-Transfer/Public Private Partnership (BOT/PPP) is a question not only of economic benefits, but more importantly, of goodwill generated by the partnership. Zhang and Jia (2010) investigate the relationship between the procedural fairness and cooperation effects in BOT/PPPs. Considering the fairness preference of the private sector, Wu, Peng, Liu, and Zhou (2018) research the governmental compensation mechanism under the income uncertainty, and they emphasize that the fairness preference is very significant for government compensation strategies. Cao, Sheng, Zhou, Liu, and Li (2014) study the incentive and supervisory mechanism when the deputy construction enterprises have fairness preference.

With the in-depth research on fairness, some scholars have focused more on the fair sharing of benefits and risks generated from a BOT project. From a more comprehensive consideration of the fairness psychology of the government and the private sector, Wang et al. (2018)

obtain a more reasonable risk allocation ratio in PPP project with the application of reciprocity preference theory. Based on the fairness preference theory, Wang and Liu (2015) determine the excess revenue-sharing ratio for PPP projects, while they only consider the private sector's fair psychology. Carbonara et al. (2014), who focus on sharing risks in a fair manner, proposed a "win-win" model to determine the concession period and apply it to a BOT project in Italy. However, the introduction of the fairness preference into the decision of concession period is still rare at present. Moreover, although the aforementioned studies mainly follow the principle of fair reciprocity, they ignore the disutility brought about by the sense of inequity.

1.3. Calculation of investment utility

Various models have been developed to calculate investment utility, and NPV is used as an analytical foundation. Most studies focus on setting economic objectives to satisfy decision makers' requirements (Carbonara et al., 2014). With this in mind, Shen et al. (2002) construct the BOT concession model (BOTCcM) for determining the concession period by using the NPV method. Using the NPV-at-risk method as one of the available criteria, Ye and Tiong (2000) incorporate the weighted average cost of capital and dual risk-return methods. Ng, Xie, Skitmore, and Cheung (2007b) consider the IRR as criterion for project evaluation and satisfy the model with three decision objectives (max IRR, min tariff regime, and min concession period). Engel et al. (2001) conduct preliminary studies by adopting the LPVR to clarify the revenue in BOT projects.

However, EPEC (2011) highlights the importance of incorporating non-financial benefits into the value for money analysis. Bao et al. (2015) consider that the investment utility is determined not only by the NPV, but also by an investor's opportunity cost. Bao and Wang (2010) propose a theoretical model to extend the NPV approach to include the social benefit factor in the concession negotiation. Scharle (2002) regards BOT as a social game, so the psychological outcome need to be considered. Based on the above studies, this study separates investment utility into two parts: economic benefits and equitable utility.

1.4. Inequity aversion theory

In reality, decision makers have both behavioral and psychological characters of fairness, reciprocity, and altruism (Fehr & Schmidt, 1999), which have been discovered and demonstrated repeatedly by behavioral and experimental economics (Samuelson, 1993). Fehr and Schmidt (1999) develop a social utility function that captured concerns about fairness in the sense of inequity aversion. This form of inequity aversion is divided into two: advantageous inequality aversion and disadvantageous inequality aversion. Advantageous inequality aversion is the loss caused by guilt because others have worse outcomes than they do, while disadvantageous inequality aversion is the loss caused by envy because others have better outcomes than they do. Therefore, the value of this social utility function lies in its exceptionally good balance between advantageous and disadvantageous inequality (Rohde, 2010). Further, Davidson, Matusz, and Nelson (2006) argue that inequality aversion is important in business. Lü, Scheve, and Slaughter (2012) provide a new methodology for analyzing the role of inequity aversion in decision making.

From the above discussion, when making concession period decisions, the government and the private sector not only focus on maximizing their personal interest, but also show preference for fairness (Carbonara et al., 2014; Wang & Liu, 2015). Therefore, this study will examine how the private sector's and the government's concerns about fairness affect the computation of the concession period, namely the distribution of risks and benefits.

2. Model development

2.1. Model assumptions

Under a BOT scheme for a toll highway, decision makers need to decide the concession period before the construction. It is assumed that the government allows the private sector to charge public price P . Denote Q_t as the traffic volume in year t , and construction cost, C , is shared equally in the construction period T_{constr} .

By considering decision makers' irrational behaviors under risks, the assumptions in this study are as follows:

1) Both sides (the government and the private sector) are bounded with rationality, and they have different fairness preferences (Simon, 2013). Furthermore, they are concerned about not only their own benefits (i.e., NPV), but also about others. Specifically, if one side's benefit is more or less than that of the other, that party will be in an inequity aversion (Fehr & Schmidt, 1999). Thus, the bounded rationality consists of two aspects: each side's minimum expectation of benefits should be satisfied, and both sides being allowed to pursue the relative fairness of benefits. Moreover, this study assumes that the principle of distributive fairness is the same investment utility-risk ratios for decision makers. The ratio is defined as $\mathrm{U}_i / CT_i (i=1,2)$, where U_i is the investment utility, and CT_i is the total investment cost.
2) Traffic volume Q_t is a risk variable which is influenced by many factors, such as social economic, population environment, consumption habits, and force majeure (Jun, 2010). Based on existing studies, this study assumes that the traffic volume varies stochastically in time following a geometric Brownian motion (GBM) (Garvin & Cheah, 2004; Iyer & Sagheer, 2011):

$$dQ_t = \mu Q_t dt + \sigma Q_t \varepsilon \sqrt{dt} \ . \tag{1}$$

For the GBM, the recursive form of the traffic volume (Q_t) in the discrete time can be written as

$$Q_{t+1} = Q_t e^{(\mu-\sigma^2/2)\Delta t+\sigma\varepsilon\sqrt{\Delta t}} , \tag{2}$$

where μ is the average annual growth rate of the traffic volume, σ is the traffic volume fluctuation rate (both μ and σ are constants), and $\varepsilon \in N(0,1)$ is the random fluctuation term.

3) The operation cost of a BOT project includes the fixed and the variable costs (Mills, 1995), which can be distinguished if it is affected by every year's traffic volume. The operating cost c_t in year t is equal to fixed cost m_t and variable cost v_t. Thus, it can be expressed as $c_t = m_t + v_t$. Fixed cost m_t is independent of the traffic volume, which includes employee wage, administrative cost, and other related costs. Therefore, fixed cost m_t can be written as $m_t = m_0 \times (1+\varphi_m)^t$, where m_0 is the initial fixed cost, and φ_m is the growth rate per annum of the fixed cost. Variable cost v_t in year t increases with the increase in traffic volume and the passage of time (Song, 2011), so it can be written as $v_t = b \times Q_t \times (1+\varphi_v)^t$, where the marginal variable cost b is a constant, and φ_v is the growth rate per annum of the variable cost.
4) The government's investment funds are mainly considered as debt funds (Ke, Wang, & Chan, 2012), while the private sector's investment funds can be both equity funds and debt funds (Roumboutsos & Anagnostopoulos, 2008).

For the government, discount rate r only needs to consider the loan interest for bank and inflation rate of the debt funds. Based on the "Fisher effect" (Fisher, 1930), r would be expressed as $r = \frac{1+i}{1+I} - 1$, where i is the bank loan interest, and I is the inflation rate.

For the private sector, the discount rate not only considers the bank loan interest and inflation rate of debt funds, but also the opportunity cost and risk premium of share capital funds. This study combines the method of the capital assets pricing model (CAPM) and the weighted average cost of capital (WACC) to calculate the private sector's risk-adjusted discount rate (RDR) (Štritof, Gelo, & Krajcar, 2009). The RDR (k) can be obtained by the following formula:

$$k = WACC;$$
$$WACC = W_E \times R_E + W_D \times R_D \times (1 - tax), \quad (3)$$

where E, D, and tax denote the equity capital, the debt capital, the tax rate, respectively; W_E is the percentage of equity capital in the capital structure, which can be written as $W_E = E / E + D$; W_D is the percentage of debt capital, which can be written as $W_D = D/(E+D)$; R_D is the cost of debt; and R_E is the cost of equity, which can be determined by the CAPM formula:

$$R_E = R_F + \beta_A (R_M - R_F), \quad (4)$$

where R_F is the risk-free return rate, β_A is the risk coefficient, and $(R_M - R_F)$ is the market risk premium.

2.2. Calculating effective concession period interval

Subsequently, T_f is the economic life and T_c is defined as the value of the concession period. NPV_1, the net present value generated during the concession period, represents the private sector's interest. NPV_2 is the government's net present value generated during the post-transfer operation within the interval $\left[T_c, T_f\right]$ (Shen et al., 2002).

Based on existing studies (Shen & Wu, 2005), the decision object can be defined as

$$NPV_1 \ge CT_1 * R_{\min}; \quad (5)$$

$$NPV_2 \ge 0, \quad (6)$$

where CT_1 is the private sector's total capital investment, and $R_{\min}$ is the private sector's expected minimum return rate from the capital investment CT_1.

According to the calculation equation of net present value, NPV_1 and NPV_2 can be written as:

$$NPV_1 = \sum_{t=1}^{T_c} \frac{(I_t - C_t)}{(1+k)^t}, \quad (7)$$

$$NPV_2 = \sum_{t=T_c+1}^{T_f} \frac{(I_t - C_t)}{(1+r)^t}, \quad (8)$$

where I_t is the income in year t which is given by $I_t = P * Q_t$; C_t is the cost in year t; k is the private sector's ROI calculated by WACC; and r is the government's discounted rate, which is described in assumption (4).

Eqns (5) and (6) express the principle that the private sector's economic benefits (NPV_1) should be no less than the expected minimum return. Moreover, the government's economic benefits (NPV_2) during the post-transfer operation period should be no less than zero (Carbonara et al., 2014; Shen et al., 2002).

Eqn (5) calculates the minimum value of the concession period ($t_{\min}$) before which the private sector cannot receive the expected minimum return on investment. Solving Eqn (6) gives the maximum value of the concession period ($t_{\max}$), after which the public interest will be lost.

If $t_{\min} > t_{\max}$, it is impossible to find a concession period to satisfy the decision subjects Eqns (5) and (6) simultaneously.

If $t_{\min} \le t_{\max}$, the concession period can be any value within the interval $[t_{\min}, t_{\max}]$. This paper mainly discusses this situation in the following context.

2.3. Determining fair and reasonable concession period

Based on assumption (5), both the private sector and the government will consider fairness. In particular, they will pay more attention to their own total investment utility, which is influenced by their benefits and inequity aversion.

Under the principle of distributive fairness, this decision model should make the difference of investment utility-risk ratios for decision makers as small as possible. Therefore, the decision model is proposed as follows:

$$\min N$$
$$\text{s.t.}\begin{cases} \left|\dfrac{U_1}{CT_1}-\dfrac{U_2}{CT_2}\right|\le N \\ N>0, U_1>0, U_2>0, CT_1>0, CT_2>0 \end{cases}, \quad (9)$$

where N is a constant; U_1 is the equitable utility of the private sector; U_2 is the government's equitable utility, CT_1 is the private sector's capital investment under risks, which includes the construction cost and the operating cost during the concession period, and can be expressed as $CT_1=\sum_{t=1}^{T_c}C_t$; and CT_2 is the government's operating cost during the post-transfer operation, which can be expressed as $CT_2=\sum_{t=T_c+1}^{T_f}C_t$. Moreover, the total utility can be written as

$$U_i = NPV_i + f_i (i=1,2), \quad (10)$$

where f_i is denoted as the disutility due to inequity, which can be calculated by the inequity aversion model (Fehr & Schmidt, 1999).

This model assumes that the one side's equitable benefit is γ times the other side's benefit, namely $\gamma_i NPV_j (i=1,2;\ j=3-i)$. In the existing research, $\gamma>0$ represents the profit distribution rule (Frazier, 1983; Macneil, 1980). In Eqn (9), the principle of distributive fairness provides the evidence for decision making, and the fair distribution rule can be expressed by $\gamma_i=\dfrac{CT_i}{CT_j}(i=1,2;\ j=3-i)$.

Specifically, if a decision maker's benefit is lower than his equitable benefit, a disadvantageous inequality occurs, which will result in the decision maker's disutility in the amount of α per unit difference in the total utility. In particular, α is the disadvantageous inequality aversion coefficient. If his benefit is more than the equitable one, an advantageous inequality occurs in the amount of β per unit difference in the total utility. Then, β is named as the advantageous inequality aversion coefficient (Fehr & Schmidt, 1999). Algebraically,

$$f_i=-\alpha_i \max\{\gamma_i NPV_j - NPV_i \cdot 0\} - \beta_i \max\{NPV_i - \gamma_i NPV_j \cdot 0\}\ (i=1,2;\ j=3-i), \quad (11)$$

where α_i and β_i are the inequality aversion coefficients of decision maker i. The assumption $\beta_i \le \alpha_i (i=1,2)$ captures the idea that a decision maker suffers more from inequality, which is to his disadvantage. We also assume $0\le\beta_i<1 (i=1,2)$; $0\le\beta_i (i=1,2)$ rules out the existence of subjects who like to be better off than others and $\beta_i<1 (i=1,2)$ means that decision maker i is prepared to sacrifice partial excess benefit in order to reduce his advantage relative to decision maker j.

3. Model application: Case study

Rong-Yu Expressway is selected as the case study, which is a BOT toll highway project in Chongqing, China. The project started in 2010 and took four years for construction, with a total investment of about USD 1.262 billion. The length of the highway is approximately 79.880 kilometers. The project life span is approximately 50 years.

3.1. Data sources

While predicting the revenue and cost, there would be many certain and uncertain variables in the decision-making process. The main certain variable in the case study is price P, which is equal to USD 5.64 per car (converted into miniature vehicles). The minimal return rate proposed by the private sector is equivalent to 15%. In assumption 4, the weight of debt in the capital structure is considered 65%; therefore, the weight of equity is 35%. The risk-free return rate is the average yield over ten-year Treasury bonds, or equivalent to 3.86%. The asset beta for this type of infrastructure is 0.6118 (Alexander, Estache, & Oliveri, 2000). The Chinese market risk premium was 7.10% (Damodaran, 2009). The cost of debt was 5.94%, which was benchmark lending rate for five years or above as set by the Bank of China in 2009, while the corporate tax was 25%. With these assumptions, the private sector's discount rate is equivalent to 6.9%. In calculating the government's discount rate, the loan interest for the bank is 5.94%; the inflation rate is approximately 3% in times of economic stability within the next four years, and therefore the government's discount rate is 2.9%.

The main uncertain variables in this case study are revenue and cost in the operation period. In assumption 2, the traffic volume will never be negative and is closely related to initial value Q_1. Based on the Original Destination Survey of existing roads, a four-stage method is used for forecasting initial value Q_1, which is 1.09 million veh/d (converted into the miniature vehicles). Using the same method, the average annual growth rate of the traffic volume is 6%. According to the maximum likelihood estimation of historical data of related projects, the traffic volume fluctuation rate is 0.1. According to assumption 3, the traffic volume is important, because the variable cost is changing with the change in traffic volume. In calculating the operating cost, the initial fixed cost is equal to USD 32.3 million.

After establishing the input data modeling, the Monte Carlo simulation approach has been used for calculating NPV. Based on the central limit theorem, the standard deviation of the simulation results is inversely proportional to the number of simulations. In other words, the precision of the Monte Carlo simulation is closely related to the number of simulations. Each simulation consists of 1,000 computer runs.

3.2. Model validation

The model can have the minimum value of the concession period ($t_{\min}$) and the maximum value of the concession

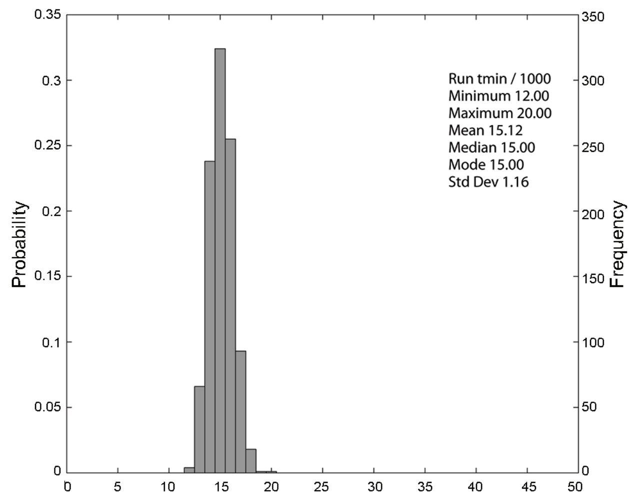

Figure 1. Probability distribution of the minimum value of concession period ($t_{\min}$)

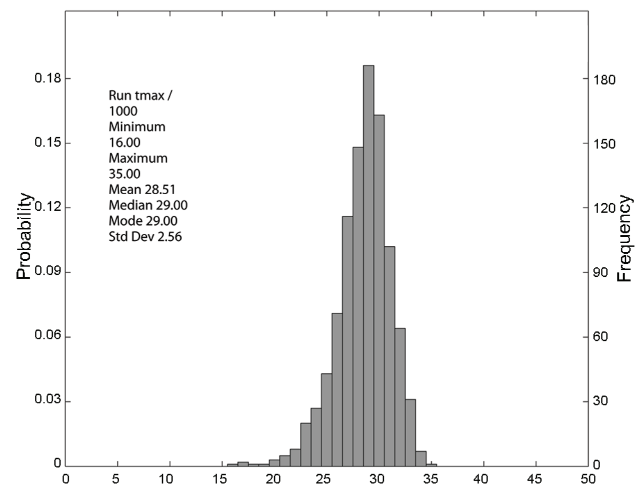

Figure 2. Probability distribution of the maximum value of concession period ($t_{\max}$)

period ($t_{\max}$) by solving Eqns (5) and (6). If $T_c < t_{\min}$, the private sector will not receive its expected minimum return, and if $T_c > t_{\max}$, the government's benefit will be damaged.

In Figure 1, $t_{\min}$ ranges over the interval $[14,16]$ years with a probability of 81.7%, a mean of 15.12 years, a mode of 15 years, and a median of 15 years. In Figure 2, $t_{\max}$ ranges over the interval $[25,32]$ years with a probability of 89.3%, a mean of 27.87 years, a mode of 28 years, and a median of 28 years.

The preliminary results (Figures 1 and 2) indicate that T_C ranges over the interval $[14,32]$ years. This means that it has a higher likelihood to satisfy the private sector's and the government's benefits. Specifically, the value of 0 represents that it is impossible to satisfy the private sector's and the government's benefits simultaneously.

After running the program 1,000 times, the probability distribution of effective values of T_c is depicted in Figure 3, where T_c ranges over the interval $[15,29]$ years with a probability of 91.5%, a mean of 21.57 years, a mode of 17 years, and a median of 21 years.

Simulating each concession period in the interval $[15,29]$ years, and each simulation consists of 1,000 computer runs. Table 1 shows the simulation results of the private sector's NPV as well as the cumulative probability of satisfying the two sides' benefit with respect to each concession period. The table shows that the longer the concession period, the more the private sector's benefits. Moreover, each concession period in the interval $[15,29]$ has an extremely high probability of satisfying the government's benefit.

From the government's perspective, promoting cooperation with the private sector is more important in satisfying its benefits. For the private sector, maximizing its own benefits is the most important (Ng et al., 2007a). Furthermore, the concession period of the toll road should not exceed 30 years, according to China's "Toll Road Administration Ordinance" regulations. Therefore, if we do not consider decision makers' fairness preference, the reasonable concession period is $T_c = 29$.

By synthetically analyzing Figures 1, 2, and 3, T_c in the interval $[15,29]$ is used to calculate the private sector's utility U_1 and the government's utility U_2.

By calculation, each concession period in the interval $[15,29]$ satisfy $U_1 > 0$ and $U_2 > 0$. However, only one concession period can minimize constant N. Specifical-

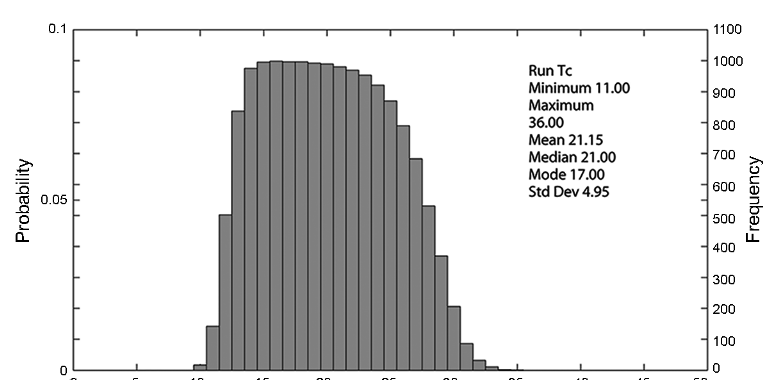

Figure 3. Probability distribution of the value of concession period (T_c)

Table 1. Simulation results of the private sector's NPV and cumulative probability of satisfying benefits of the government and the private sector

Concession period (years)	Mean of the private sector's NPV (million USD)	Std Dev of the private sector's NPV (million USD)	The private sector (%)	The government (%)
15	2.504	0.933	92.8	100
16	3.358	1.001	98.5	100
17	4.279	1.101	99.9	100
18	4.960	1.107	100	100
19	5.840	1.220	100	100
20	6.474	1.246	100	100
21	7.261	1.254	100	100
22	8.042	1.354	100	100
23	8.763	1.436	100	100
24	9.425	1.408	100	100
25	10.011	1.504	100	100
26	10.740	1.508	100	100
27	11.430	1.569	100	100
28	11.998	1.526	100	100
29	12.666	1.637	100	100

ly, the fair concession period can make the difference of investment utility-risk of the government and the private sector minimum. From Eqn (9), we have 1,000 fair values of T_c after 1,000 simulations; then, we calculate the probability of every reasonable value of T_c (see Figure 4). In Figure 4, the probability of $T_c = 25$ has the highest frequency. Therefore, $T_c = 25$ is the value of the fair concession period.

The disutility due to inequity is an important part of total utility. In Eqn (11), we find that decision makers' inequality aversion coefficients are hard to measure accurately in the cases of both disadvantageous and advantageous inequalities. Therefore, we have to explore the possible impact of fluctuating inequality aversion coefficients on the above reasonable concession period.

Figure 5 shows that when the two sides' inequality aversion coefficients reduce by 1/2, expand 4 times, or 18 times simultaneously, the value of 25 years has the highest probability. Until the coefficients expand 32 times, the reasonable concession period becomes 24 years. Therefore, we can see that the result based on the fairness preference is stable within the certain error range of equality aversion coefficients.

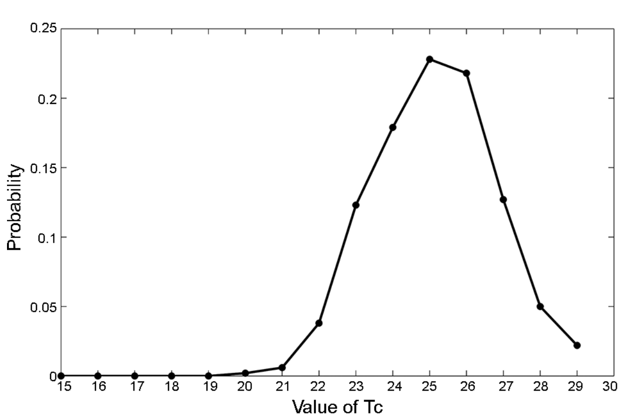

Figure 4. The probability of constant N corresponding to the minimum T_c

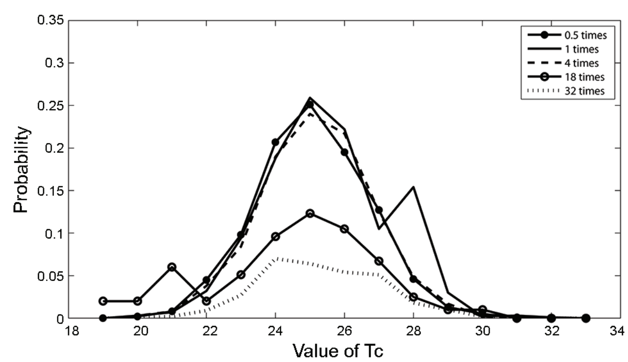

Figure 5. The probability of the value of T_c based on the fluctuant inequality aversion coefficients

Without the fairness preference, the concession period is equal to 29. Figure 6(a) shows that when $T_c = 29$, the private sector's investment utility-risk ratio is apparently higher than that of the government. This means that the private sector gains much exceptional profit. This is a phenomenon of unfair profit distribution and another form of the loss of state assets.

With the fairness preference, the concession period is equal to 25. Figure 6(b) shows that when $T_c = 25$, the difference is not obvious anymore. It means that inducing the fairness preference in calculating the concession period can narrow the gap between the two sides' investment utility-risk ratios. Consequently, the fairness of the profit distribution can be better guaranteed.

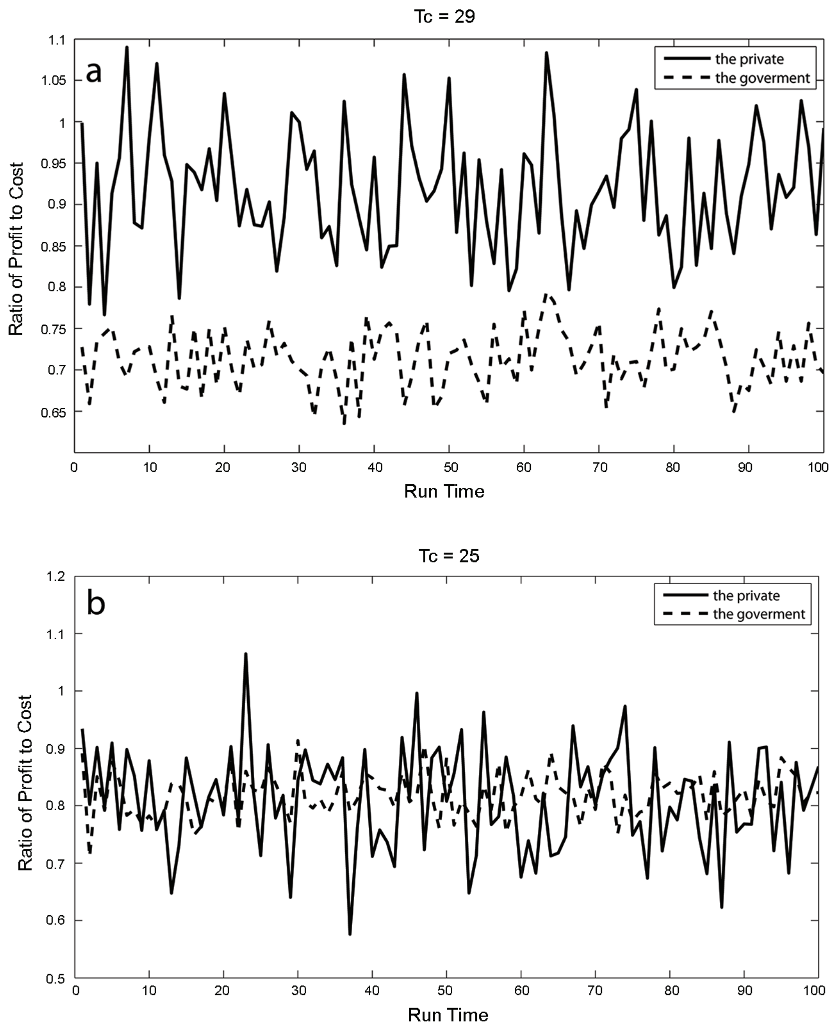

Figure 6. The difference between the both sides' ratio of profit to cost with the fairness and without the fairness

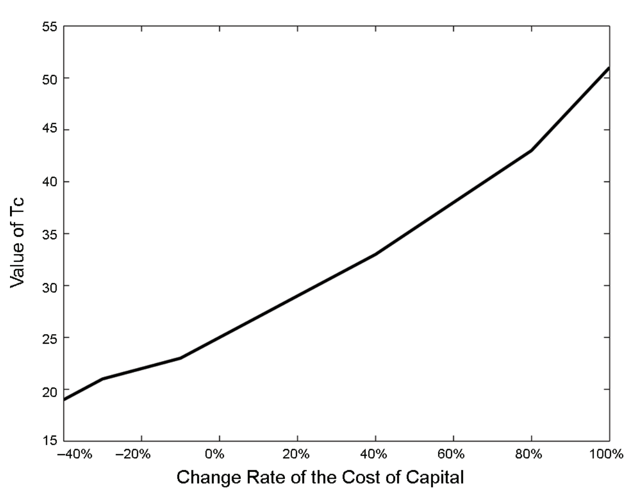

Figure 7. Sensitivity analysis of the discount rate changes

3.3. Sensitivity analysis

To explore the likely influence on the outcome of Monte Carlo simulation, sensitivity analysis of private sector's discount rate k and government's discount rate r was conducted, considering the result in Figure 7.

Figure 7 indicates that the value of T_c increases with the change in discount rates. When the change rate is over 80%, the growth rate of the value of T_c becomes higher. In this text, a change rate of 10% is equivalent to the numerical change of 0.004–0.006. When the change rate is over 100%, the concession period cannot be found in the project life cycle. Hence, the result of the sensitivity analysis shows that the discount rate has an important influence on the concession period decision.

Conclusions

This study develops a concession model for a fair distribution of benefits and risks in a BOT road project. The model in this study creatively introduces the inequity aversion theory to describe decision makers' irrational behavior under risks. To ensure a fair distribution of benefits and risks, this study sets the principle of fairness to existing investment utility-risk ratios. Based on Monte Carlo simulation, this study verifies the application of the model using a case study of a BOT road in China.

By introducing the inequity aversion theory into the concession model, this study provides a novel perspective to explore the distribution of benefits and risks in a BOT project. This research has theoretical and practical significance in promoting the cooperation between the government and the private sector. The following theoretical implications can be drawn from this study: (1) the concession period with the fairness preference can effectively narrow the gap between the investment utility-risk ratios of the government and the private sector, thus guaranteeing the distribution fairness of benefits and risks in a BOT project. Therefore, when making a BOT contract, the government will need to identify the strength of the private sector's fairness preference, using personality and other psychological tests (Wang et al., 2018). (2) The investors' investment utility is affected by their emotions (Wang & Liu, 2015). Thus, decision makers' investment utility contains not only economic benefits, but also the disutility brought about by the sense of inequity. (3) The risk discount rate has an important influence on determining the concession period (Carbonara et al., 2014). Therefore, the investments risks of decision makers from the government and the private sector should be measured respectively from the perspective of their own funding sources.

The practical implication of the study is that it can assist decision makers in making the BOT contract more fair and efficient. Because of the fairness preference, if concession period is lower than the fair value, the private sector's degree of effort and his desire to invest will be reduced. However, if the concession period is too long, it is difficult to guarantee benefits to the public (Zhang & Jia, 2010). Therefore, considering the fairness preference of both sides in decision making has a strong practical value in ensuring the satisfaction and investment enthusiasm of the private sector and in maximizing public utility.

Finally, one of the limitations of this study is that the use of Monte Carlo simulation may pose difficulties for decision makers in predicting all uncertain variables. Future study needs to identify key variables by collecting more information on the decision-making process, and to assign the probability distribution of uncertain variables more accurately.

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Author contributions

Xue Yan and Qian Li conceived the study and were responsible for the Introduction, Model development and Conclusions. Heap-Yih Chong were responsible for Model application. Jing Zhou were in charge of the literature review and the coordination of the article.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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