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Comparison of royalty methods for build–operate–transfer projects from a negotiation perspective

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ABSTRACT

This study constructs a royalty negotiation model for the bi-level programming (BLP) problem and develops a heuristic algorithm for solving the BLP problem. Concession rate, learning effect, and the time value discount rate are integrated into the proposed algorithm to reflect an authentic negotiation process. A case study is employed to simulate the negotiation behavior of two parties and alternative royalty strategies are discussed. Analytical results indicate that the two parties acquire the best negotiation result during the fifth negotiation. The operational revenue-based royalty model is more preferred by governments, while concessionaires favor more the operational output-based royalty model.

1. Introduction

The build, operate, and transfer (BOT) approach is one of the private-public participation project (PPP) types for implementing public infrastructure projects in developing and developed countries. The purposes of adopting the BOT approach for carrying out infrastructure projects are to reduce the government financial burden and to enhance the efficiency in construction and operation (Finnerty, 1996). Renowned examples of BOT projects in the world include the Eurotunnel project, the Euro Disneyland in France, the north–south highway in Malaysia, the Tribasa Toll Road project in Mexico (Walker and Smith, 1996; Finnerty, 1996), the High-Speed Rail BOT (HSRBOT) project and the Taipei Port Container Logistic BOT project in Taiwan (Public Construction Commission, 2001).

In the literature, Tang et al. (2010) reviewed popular research topics and found out that the three mainstream research issues in the PPP area are risks, relationships, and financing. The financial viability of BOT projects has been regarded as one of the critical factors for implementing the infrastructure BOT projects (Chen et al., 2002; Chiou and Lan, 2006; Finnerty, 1996), and it varies with factors such as operation revenue, costs, discount rate and so on. In view of this characteristic, two scenarios may occur during the concession period; one is that the private sector might get excessive profit from the BOT project; and the other is that the private investors are likely to go bankrupt due to the financial deficit in the BOT project. The first scenario may result in controversy for society because the private sector obtains the property right of the BOT project from the government for operating the project; while the second scenario will cause tremendous loss in finance or economic benefit of society once the concessionaire ceases operating the BOT project. To prevent the above scenarios from occurring, the government can collect royalty from the concessionaire with excessive profit gained from "public goods"

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during the concession period; on the other hand, the government can stop collecting royalty from the concessionaire with deficit to improve the financial viability of the BOT project. Hence, besides factors including concession period, revenue, and discount rate, royalty also has a significant impact on the financial viability of BOT projects.

Many royalty computation methods, such as pre-tax profit-based royalty, total-revenue-based royalty, lump-sum royalty, patronage-based royalty, and operational output-based royalty, can be adopted by a government or the private sector (Chiou and Lan, 2006). For instance, the levied lump-sum royalty of NT$30 billion for Taiwan's 101 Skyscraper BOT Project in 1998 was calculated using the fixed royalty method. The levied royalty of US$10 million for the Malaysia north–south highway BOT project was also determined by the fixed royalty method. For the HSRBOT project in Taiwan, the royalty paid by the concessionaire to the government included 10% of pre-tax annual operational revenue; however, there was no royalty scheme for the Kaohsiung MRT BOT project because of its poor financial condition. (Public Construction Commission, 2001). For the Euro Disneyland BOT project, the royalty was calculated according to the percentage of gross revenue of operation items during the concession period (Finnerty, 1996).

From the project financing viewpoint, the royalty the concessionaire pays a government is a cost expenditure in project discount cash flow for a BOT project. Some BOT cases lay down the royalty scheme in the BOT agreement after negotiation between both private and public parties. Such scheme becomes the resource of renewal or maintenance expenditure of facility because it can be regarded as a revenue-sharing scheme developed through a bargaining process for royalty determination between two parties (Finnerty, 1996). However, as indicated in Tang et al. (2010), previous studies have focused on three themes including risks of PPP, the relationship between organizations within the public and private sectors, and different financing models in the PPP area. Issues of the royalty strategy or royalty formula of BOT project have not yet been investigated.

Some studies constructed royalty formulas using mathematical programming, simulation, or financial engineering methods. For instance, Chiou and Lan (2006) developed many royalty models that involve pre-tax profit, total revenue, and patronage using mathematical programming and fuzzy mathematical programming to derive the royalty for a BOT project. Kang et al. (2004, 2007) constructed a financial decision-making model that describes the royalty relationship between government investment and private investment using mathematical programming. The methods developed by Kang et al. (2003, 2004, 2007) for determining royalties for BOT projects can benefit both governments and the private sector. Most studies, however, did not determine royalties from a negotiation perspective.

Some recent studies have employed the game theory or bi-level programming (BLP) approaches to determine the royalty and operational output level, or to identify the concession period for a BOT project. For instance, Yang and Meng (2000) examined the toll scheme for highway networks using BLP under the BOT scheme. Xing and Wu (2001) used BLP to construct the Stackelberg Game Model for determining the price and production output of a power utility in a BOT project. Shen et al. (2007) utilized Bargaining Game Theory to identify the concession period of a BOT project. They developed a BOT concession model to identify a specific concession period which considers the bargaining behavior of the two parties in a BOT contract. Additionally, Kang et al. (2010) also developed a royalty model using the BLP approach to determine the royalty for a BOT project, which is calculated according to the total revenue. Notably, other royalty computation methods have not been investigated. Determining which royalty method suits governments and which suits private sectors warrants investigation. This study compares alternative royalty strategies from the negotiation perspective. The remainder of this paper is organized as follows. Section 2 gives the assumptions of the proposed model. Section 3 constructs three royalty negotiation models and applies a heuristic algorithm to solve the BLP problem. Section 4 presents a numerical example. Finally, findings are discussed and conclusions are given in Section 5.

2. Assumptions in the proposed model

Assumptions in model development were as follows.

(1) We assume lump-sum royalty, operational revenue-based royalty, and operational output-based royalty methods can be adopted by both parties to determine the royalty for a BOT project. We also assume the three models are independent.
(2) Two parties, a government and a private investor, establish a relationship within a BOT contract through negotiations conducted via rational behavior. Rational behavior means both parties will adequately compare all possible outcomes to protect their interests and profit-making objectives.
(3) The two parties are entitled to the same full and frank disclosure of relevant information related to a BOT project. Furthermore, the parties communicate clearly and effectively.

3. Methodology

3.1. Concept of BOT project financing

The concept for financing projects proposed by Kang et al. (2003, 2004) was utilized to describe the annual royalty relationship between a government and private firm. Fig. 1 shows this concept.

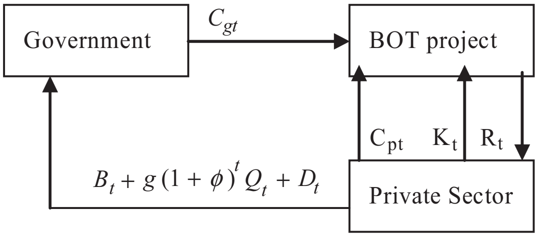

Fig. 1. Concept of annual royalty in BOT projects; the operational output-based case.

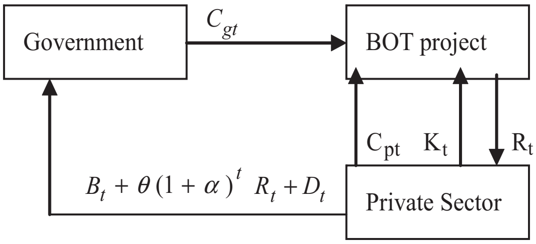

Fig. 2. Concept of an annual royalty in a BOT project: the operational revenue-based case.

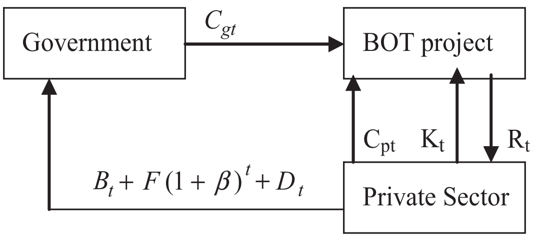

Fig. 3. Concept of annual royalty in a BOT project: the lump-sum royalty case.

A concessionaire and a government fund the construction and operation of a BOT project. Construction cost of a project comprises C_{gt} and C_{pt}; where C_{gt} and C_{pt} are government investment cost and private investment cost at time t during the construction period, respectively; and K_t is the nominal operation cost at time t during the operation period. The concessionaire pays $B_t + g(1+\phi)^t Q_t + D_t$ to the government according to operational output and related business income, where B_t is land rent at time t, Q_t is operational output at time t, and D_t is tax at time t. The $B_t + g(1+\phi)^t Q_t + D_t$ term (Fig. 1) is the sum of land rent, royalty, and tax. Let g be the proportion of operational output of a BOT project during the operating period, and let ϕ be the annual growth rate of g. As in $g(1+\phi)^t Q_t$, royalty variation depends on changes to g, Q_t, ϕ or t; that is, royalty variation increases as g, Q_t, ϕ or t increases.

A causal relationship exists among royalty, government investment, private sector investment, and the government finance recovery ratio in cash flow for a BOT project. The government finance recovery ratio was derived by Kang et al. (2007) as "government income divided by government investment cost; government income includes the royalty, land rent, and tax needed to cover its investment cost." From this perspective, a government can use this ratio to replace a conventional evaluation index, such as Net Present Value (NPV), when assessing the ability to recover investment from project financing. If the royalty the land rent and tax change, then it will have a significant effect on the government finance recovery ratio and net income for the government and private sector.

Similarly, this study uses the BOT project financing concept (Fig. 1) to elucidate the relationships among royalty, government investment, and private investment in the operational revenue-based royalty and lump-sum royalty schemes. Figs. 2 and 3 show the operational revenue-based case and the lump-sum royalty case, respectively.

The definitions for D_t, K_t, C_{gt}, C_{pt}, B_t, and t in the operational revenue-based case (Fig. 2) and lump-sum royalty case (Fig. 3) are the same those on the operational output-based case (Fig. 1). In the operational revenue-based case, $B_t + \theta(1+\alpha)^t R_t + D_t$ is the sum of land rent, royalty, and tax; where R_t is operating revenue at time t; $\theta(1+\alpha)^t R_t$ is royalty, which varies according to R_t, t, and θ; where θ is the proportion of operating revenue from a BOT project at time t. Thus, $B_t + \theta(1+\alpha)^t R_t + D_t$ indicates that the concessionaire should pay land rent, a royalty, and tax to the government. In the lump-sum royalty case, the royalty $F(1+\beta)^t$ also varies according to t, β and F; where F is the annual project royalty, and β is growth rate of the annual royalty.

Differences in a royalty depend on $F(1+\beta)^t$, $\theta(1+\alpha)^t R_t$, and $g(1+\phi)^t Q_t$ for the lump-sum royalty case, the operational revenue-based case, and the operational output-based case, respectively (Figs. 1–3).

3.2. The model

Following the concepts of the operational output-based case (Fig. 1), the operational revenue-based case (Fig. 2) and the lump-sum royalty case (Fig. 3), the royalty can be computed in three ways—the royalty is based on operational output of a BOT project; the royalty is based on the operating revenue of a BOT project; and the royalty is a lump-sum fee for a BOT project. The three royalty models are described as follows.

A. Model I (the operational output-based royalty model): Royalty depends on operational output of a project; the annual nominal royalty is computed using $g(1+\phi)^t Q_t$. The value of g is negotiated by the two parties.
B. Model II (the operating revenue-based royalty model): Royalty depends on project operating revenue; the annual nominal royalty is computed using $\theta(1+\alpha)^t R_t$. The value of θ is negotiated by the two parties, and the royalty can be obtained.
C. Model III (the lump-sum royalty model): Royalty is a lump-sum project franchise fee; the annual nominal royalty is computed using $F(1+\beta)^t$. Once the value of F is determined through negotiation between the two parties, the lump-sum royalty is obtained.

When the concession period changes, price regulation, price flexibility, or price adjustment schemes for output result in revenue changes for the private sector during the operational period. Generally, the price cap scheme and minimum guarantee of production output or operations will be signed or negotiated in a BOT contract to improve efficiency or reduce the number of uncertain operational factors for the private sector. Considering the concession period of a project and the minimum guarantee output scheme for a government results in massive variation in operating revenue, even though operating revenue is an output function. The operating revenue-based and operational output-based models in this study should be used to investigate the negotiation behavior of and royalty for the two participating parties.

To develop a royalty negotiation model for the operational output-based case, we assume the concession period of a BOT project comprises the construction period ($t = 0 \sim n$) and operation period ($t = n+1 \sim N$). We also assume the government does not offer affiliated business income, joint-development income, and no subsidies to the private sector; notably, this study does not consider the salvage value of fixed assets in a BOT project. After the concession period expires, the facilities in a BOT project are typically returned unconditionally to the government. Moreover, we assume government investment is totally capitalized by debt. Government planning cost is not considered. Additionally, we assume the royalty is not tax-deductible. The capital cost of a BOT project is evaluated using the Weighted Average Cost of Capital (WACC) approach.

A causal relationship exists among the royalty, government investment, private sector investment, and the government finance recovery ratio in cash flow for a BOT project (Fig. 1). The government finance recovery ratio was derived by Kang et al. (2004, 2007) as

$$\Pi_{g,Q}(k) = \frac{1}{C_g}[r_g + g_u(k) \times f_{g,Q}] = \frac{1}{C(1-P_C)}[r_g + g_u(k) \times f_{g,Q}] \tag{1}$$

where $r_g = \sum_{t=0}^{N} \frac{B_t + D_t}{(1+i)^t}$, $f_{g,Q} = \sum_{t=h}^{N} \frac{(1+\varphi)^{t-h} Q_t}{(1+i)^t}$, which is a discount factor of the operational output-based royalty model for a project, and $P_C = \frac{C_p}{C} = \frac{C_p}{C_g + C_p}$; where P_C is the rate of a concessionaire's investment cost; C is the sum of current construction costs, which is discounted to the first year of the construction period; C_g is the sum of the present value of construction costs financed by a government, and this cost is discounted to the first year of the construction period; C_p is the sum of the present value of construction costs financed by private investment, and this cost is discounted to the first year of the construction period; and i is the interest rate for government bonds. Notably, $g_u(k)$ is the g value, which is the proportion of operational output of a BOT project during the operating period at the kth negotiation by the government; that is, $g_u(k)$ is a decision variable of the upper-level programming problem at the k th negotiation.

Eq. (1) derives the government finance recovery ratio, $\Pi_{g,Q}(k)$, at the kth negotiation. A positive relationship exists between $\Pi_{g,Q}(k)$ and $(r_g + g_u(k) \times f_{g,Q})$; that is, as the royalty, tax, and land rent for host utilities increase, $\Pi_{g,Q}(k)$ increases. Thus, $\Pi_{g,Q}(k)$ increases when r_g, $g_u(k)$, and $f_{g,Q}$ increase. Conversely, $\Pi_{g,Q}(k)$ decreases when P_C increases or r_g, $g_u(k)$, and $f_{g,Q}$ decrease.

Let $\Pi_{p,Q}(k)$ be the profit index of the concessionaire:

$$\Pi_{p,Q}(k) = \frac{N_I - g_\ell(k) \times f_{p,Q}}{C_P} \tag{2}$$

where $N_I = \sum_{t=n+1}^{N} \frac{R_t - C_t - B_t - D_t}{(1+d)^t}$; where N_I is the total revenue of a BOT project, including operating revenue and non-operating revenue; $g_\ell(k)$ represents the g value, which is based on the proportion of operational output of a BOT project during the operating period at the kth negotiation of the private sector; and $g_\ell(k)$ is a decision variable of the low-level programming problem at the kth negotiation. Additionally, $f_{p,Q} = \sum_{t=h}^{N} \frac{(1+\varphi)^{t-h} Q_t}{(1+d)^t}$; where d is the risk-adjusted discount ratio after tax for the concessionaire. Let $d > i$; thus, d can be estimated by the WACC with corporate tax as

$$d = d_B \times (1 - T_c) \times \left(\frac{B}{S+B}\right) + d_S \times \left(\frac{S}{S+B}\right) \tag{3}$$

where d_B is the cost of long-term debt of a BOT project for a private firm; d_S is the cost of equity of a BOT project for a private firm; B is the market value of debt of a BOT project for a private firm; T_c is the marginal tax ratio of a BOT project; and S is the market value of equity of a BOT project for a private firm.

The numerator of Eq. (2) is net operating income minus the royalty at the kth negotiation, and the denominator of Eq. (2) is investment cost for the concessionaire for a project during the construction period. Eq. (2) represents the profitability for the private sector at the kth negotiation, indicating that the concessionaire pursues maximum profit during the kth negotiation when the private sector is a rational decision-maker.

Based on Eq. (1), the government finance recovery ratios for the operating revenue-based model and lump-sum royalty model are derived by Eqs. (4) and (5), respectively:

$$\Pi_{g,R}(k) = \frac{1}{C_g}[r_g + \theta_u(k) \times f_{g,R}] = \frac{1}{C(1-P_C)}[r_g + \theta_u(k) \times f_{g,R}] \tag{4}$$

$$\Pi_{g,F}(k) = \frac{1}{C_g}[r_g + F_u(k) \times f_{g,F}] = \frac{1}{C(1-P_C)}[r_g + F_u(k) \times f_{g,F}] \tag{5}$$

Eqs. (4) and (5) also derive $\Pi_{g,R}(k)$ and $\Pi_{g,F}(k)$ at the kth negotiation. Thus, both $\Pi_{g,R}(\cdot)$ and $\Pi_{g,F}(\cdot)$ are functions of k. In Eq. (1), a positive relationship exists between the government finance recovery ratio and the royalty for the operational revenue-based model and lump-sum royalty model. The profit index also implies that as the royalty, tax, and land rent host government acquire increase, the government finance recovery ratio increases.

Additionally, based on Eq. (2), the profit index of the concessionaire for the operating revenue-based royalty model and the lump-sum royalty model are derived by Eqs. (6) and (7), respectively:

$$\Pi_{p,R}(k) = \frac{N_I - \theta_\ell(k) \times f_{p,R}}{C_P} \tag{6}$$

$$\Pi_{p,F}(k) = \frac{N_I - F_\ell(k) \times f_{p,F}}{C_P} \tag{7}$$

where $f_{p,R} = \sum_{t=h}^{N} \frac{(1+\alpha)^{t-h} R_t}{(1+d)^t}$ and $f_{p,F} = \sum_{t=h}^{N} \frac{(1+\beta)^{t-h}}{(1+d)^t}$ are the discount factors of the operating revenue-based royalty model and lump-sum royalty model, respectively. Both θ_ℓ and F_ℓ are functions of k.

According to Wen and Hsu (1991), the BLP problem is a Stackelberg game, an n-person non-cooperative game with leader–follower strategy conception. This model is for a sequential decision for two players who pursue maximized goals, which are subject to another decision-making strategy. The host utility can be regarded as the upper-level problem of the BLP problem because the royalty was first announced by the government in a BOT tender. The private sector will then negotiate the royalty with the government. Hence, the private sector can be regarded as the lower-level problem of the BLP problem. The upper-level problem and lower-level problem were formulated as follows.

Model I: The operational output-based royalty model

[Upper-level problem]:

$$\underset{\{g_u(k)\}}{Max}\ \Pi_{g,Q}(k) = \frac{1}{C_g}[r_g + g_u(k) \times f_{g,Q}] = \frac{1}{C(1-P_C)}[r_g + g_u(k) \times f_{g,Q}] \tag{8}$$

$$s.t. g_u(k) \times f_{g,Q} + C \times \Pi_{G0} \times P_C \geqslant C \times \Pi_{G0} - r_g \tag{9}$$

$$g_u(k) \leqslant (N_I - P_C \times C)/f_{p,Q} \tag{10}$$

$$g_u(k) \geqslant V_\ell(k) \tag{11}$$

$$g_u(k) \leqslant W_u(k) \tag{12}$$

[Lower-level problem]:

$$\underset{\{g_\ell(k)\}}{Max}\ \Pi_{p,Q}(k) = \frac{N_I - g_\ell(k) \times f_{p,Q}}{C_P} \tag{13}$$

$$s.t g_\ell(k) \times f_{g,Q} + C \times \Pi_{G0} \times P_C \geqslant C \times \Pi_{G0} - r_g \tag{14}$$

$$g_\ell(k) \leqslant (N_I - P_C \times C)/f_{p,Q} \tag{15}$$

$$g_\ell(k) \geqslant V_\ell(k) \tag{16}$$

$$g_\ell(k) \leqslant W_u(k) \tag{17}$$

where $V_\ell(k)$ is the lower bound value of a feasible solution at the kth negotiation for the lower-level problem; $W_u(k)$ is the upper bound value of a feasible solution at the kth negotiation for the upper-level problem; and $g_\ell(k)$ and $g_u(k)$ are decision variables in the BLP problem. Both $g_\ell(k)$ and $g_u(k)$ are derived by Eqs. (1) and (2), respectively.

The objective function of the upper-level problem in Eq. (8) indicates that the host utility maximizes its financial recovery rate when joining a BOT project. Thus, as the royalty a government collects increases, the $\Pi_{g,Q}(k)$ index increases. Eqs. (9)–(12) are constraints of the upper-level problem. Eq. (9) indicates that the host utility should collect a royalty above a minimum from the concessionaire to meet the minimum financial recovery rate, Π_{G0}. Moreover, let Π_{G0} be a constant. Eq. (10) indicates that the royalty has been delivered by the private sector to the host utility, which has an upper bounded value for avoiding operating deficits. Thus, $((N_I - P_C \times C)/f_{p,Q}) \geqslant 0$ holds because $g_u(k)$ is not a negative value. The upper and lower bounded solutions are $g_u(k) \geqslant V_\ell(k)$ and $g_u(k) \leqslant W_u(k)$ for the upper-level problem, respectively.

The objective function of the lower-level problem indicates that the private sector hopes to reduce the royalty and maximize its profit during each negotiation. Eqs. (14)–(17) are constraints in the lower-level problem from; the uses of Eqs. (14) and (15) are the same as those of Eqs. (9) and (10); and $g_\ell(k) \geqslant V_\ell(k)$ and $g_\ell(k) \leqslant W_u(k)$ are the upper and lower bounded solutions for the lower-level problem, respectively.

Following the formulation concept of the BLP of the operational output-based royalty model, this work formulates BLP problems for models II and III. The BLP problem for model II is formulated as

Model II: The operating revenue-based model

[Upper-level problem]:

$$\underset{\{\theta_u(k)\}}{Max}\ \Pi_{g,R}(k) = \frac{1}{C_g}[r_g + \theta_u(k) \times f_{g,R}] = \frac{1}{C(1-P_C)}[r_g + \theta_u(k) \times f_{g,R}] \tag{18}$$

$$St \theta_u(k) \times f_{g,R} + C \times \Pi_{G0} \times P_C \geqslant C \times \Pi_{G0} - r_g \tag{19}$$

$$\theta_u(k) \leqslant (N_I - P_C \times C)/f_{p,R} \tag{20}$$

$$\theta_u(k) \geqslant V_\ell(k) \tag{21}$$

$$\theta_u(k) \leqslant W_u(k) \tag{22}$$

[Lower-level problem]:

$$\underset{\{\theta_\ell(k)\}}{Max}\ \Pi_{p,R}(k) = \frac{N_I - \theta_\ell(k) \times f_{p,R}}{C_P} \tag{23}$$

$$s.t \theta_\ell(k) \times f_{g,R} + C \times \Pi_{G0} \times P_C \geqslant C \times \Pi_{G0} - r_g \tag{24}$$

$$\theta_\ell(k) \leqslant (N_I - P_C \times C)/f_{p,R} \tag{25}$$

$$\theta_\ell(k) \geqslant V_\ell(k) \tag{26}$$

$$\theta_\ell(k) \leqslant W_u(k) \tag{27}$$

Model III: The lump-sum royalty model.

The BLP problem for the lump-sum royalty model is formulated as

[Upper-level problem]:

$$\underset{\{F_u(k)\}}{Max}\ \Pi_{g,F}(k) = \frac{1}{C_g}[r_g + F_u(k) \times f_{g,F}] = \frac{1}{C(1-P_C)}[r_g + F_u(k) \times f_{g,F}] \tag{28}$$

$$s.t. F_u(k) \times f_{g,F} + C \times \Pi_{G0} \times P_C \geqslant C \times \Pi_{G0} - r_g \tag{29}$$

$$F_u(k) \leqslant (N_I - P_C \times C)/f_{p,F} \tag{30}$$

$$F_u(k) \geqslant V_\ell(k) \tag{31}$$

$$F_u(k) \leqslant W_u(k) \tag{32}$$

[Lower-level problem]:

$$\underset{\{F_\ell(k)\}}{Max}\ \Pi_{p,F}(k) = \frac{N_I - F_\ell(k) \times f_{p,F}}{C_P} \tag{33}$$

$$s.t.\ F_\ell(k) \times f_{g,F} + C \times \Pi_{G0} \times P_C \geqslant C \times \Pi_{G0} - r_g \tag{34}$$

$$F_\ell(k) \leqslant (N_I - P_C \times C)/f_{p,F} \tag{35}$$

$$F_\ell(k) \geqslant V_\ell(k) \tag{36}$$

$$F_\ell(k) \leqslant W_u(k) \tag{37}$$

The decision variables in model II are $\theta_\ell(k)$ and $\theta_u(k)$, and $F_\ell(k)$ and $F_u(k)$ are the decision variables in model III.

3.3. Algorithm for the BLP problem

Many algorithms for the BLP problem, including the vertex enumeration or Kuhn–Tucker transformation approaches, have been applied to find the optimal solution (Wen and Hsu, 1991; Liu and Stephen, 1994). The vertex enumeration approach uses the simplex algorithm to find a feasible solution to the upper-level problem of the BLP problem, while the Kuhn–Tucker transformation approach converts the objective function of the low-level problem into constraints for the upper-level problem. However, to identify the comprisal solution for the operational output-based royalty model, this study applied a heuristic algorithm to the BLP problem. The steps in the proposed heuristic algorithm are as follows.

Step 0: Let $k = 0$ and $k = k + 1$.
Step 1: Derive a feasible solution for the upper-level problem.
Step 2: Derive a feasible solution for the lower-level problem.
Step 3: Test these feasible solutions for the BLP problem. If all solutions converge, then it is the comprisal solution; otherwise, go to Step 4.

In Step 3, this study set the convergence test by which the difference between the royalty expected by a government and the royalty a private sector firm is willing to pay is smaller than a tolerance of error. This condition is defined as

$$\left|\frac{\theta_u(k) - \theta_\ell(k)}{\theta_\ell(k)}\right| \leqslant \delta \text{ and } \left|\frac{\theta_u(k) - \theta_\ell(k)}{\theta_u(k)}\right| \leqslant \delta \tag{38a}$$

where δ is the tolerated error; we assume $\delta = 0.01$. If solutions to the BLP problem satisfy the convergence test criterion, then royalty negotiation stops.

Additionally, Eq. (38a) is replaced with Eqs. (38b) and (38c) to derive the operational output-based royalty model and lump-sum royalty model, respectively.

$$\left|\frac{g_u(k) * f_g - g_\ell(k) * f_p}{g_\ell(k) * f_p}\right| \leqslant \delta \text{ and } \left|\frac{g_u(k) * f_g - g_\ell(k) * f_p}{g_u(k) * f_g}\right| \leqslant \delta \tag{38b}$$

$$\left|\frac{F_u(k) - F_\ell(k)}{F_\ell(k)}\right| \leqslant \delta \text{ and } \left|\frac{F_u(k) - F_\ell(k)}{F_u(k)}\right| \leqslant \delta \tag{38c}$$

Step 4: Set the initial concession rates for the two parties, and let $k \neq 0$. Substitute the concession rates into Eqs. (39), (40), and derive $V_\ell(k + 1)$ and $W_u(k + 1)$.
Step 5: Derive the concession rates for the next negotiation, $r_u(k + 1)$, and $r_\ell(k + 1)$, and find $g_\ell(k + 1)$ and $g_u(k + 1)$.
Step 6: Repeat steps 0–5. The solution to the BLP problem is obtained when the convergence test of the solution holds; otherwise, no solution exists, and the algorithm is stopped.

Although Chen et al. (2002), Xing and Wu (2001), Yang and Meng (2000) utilized the BLP model to determine the price (or toll) and road capacity investment using different algorithms under the BOT scheme, they did not explore the effect of the learning effect, concession rate, and time value discount, on player changes. Nevertheless, these factors, which are regarded as factors associated with bargaining cost, as addressed by Cross (1965), have significant effects on the bargaining process. Thus, these factors associated with bargaining cost have been incorporated into BOT bargaining models (Shen et al., 2007; Lin and Chang, 2005). Following the work by Cross (1965), this work defines the concession rate of the government and that of a private firm. The concession rates for both parties are derived by Eqs. (39) and (40), respectively.

$$r_u(k) = \frac{(buvr_\ell(k-1) + (ab(1-\frac{v}{2})(1+\frac{u}{2}) - uv)r_u(k-1))}{(ab(1+\frac{u}{2})(1+\frac{v}{2}) - uv)} \tag{39}$$

$$r_\ell(k) = \frac{(auvr_u(k-1) + (ab(1-\frac{u}{2})(1+\frac{v}{2}) - uv)r_\ell(k-1))}{(ab(1+\frac{u}{2})(1+\frac{v}{2}) - uv)} \tag{40}$$

where $r_u(k)$ and $r_\ell(k)$ are the concession rates at the kth negotiation for the upper-level and lower-level programming problems, respectively; similarly, $r_u(k-1)$ and $r_\ell(k-1)$ are the concession rates at the $(k-1)$th negotiation; and a and b are time value discounts of the upper-level and lower-level programming problems, respectively. Let a and b be constant values. Let μ and v be the learning rates for the upper-level and lower-level programming problems, respectively. We also assume μ and ν are constants.

Eq. (39) indicates that the concession rate for the kth negotiation for the upper-level programming problem is affected by $r_\ell(k-1)$, $r_u(k-1)$, u, v, a, and b. Similarly, $r_\ell(k)$ in Eq. (40) is affected by $r_\ell(k-1)$, $r_u(k-1)$, u, v, a, and b. Obviously, royalty negotiation of the host utility or concessionaire is reflected in the concession rates of the two parties. Then, Eqs. (39) and (40) are substituted into Eqs. (41)–(44) and $W_u(k+1)$ and $V_\ell(k+1)$ are modified in the upper-level and lower-level programming problems, respectively.

$$W_u(k+1) = W_u(k) - W_u(k) \times r_u(k) \tag{41}$$

$$V_\ell(k+1) = V_\ell(k) + V_\ell(k) \times r_u(k) \tag{42}$$

$$W_u(k+1) = W_u(k) - W_u(k) \times r_\ell(k) \tag{43}$$

$$V_\ell(k+1) = V_\ell(k) + V_\ell(k) \times r_\ell(k) \tag{44}$$

where $W_u(k)$ and $V_\ell(k)$ are the upper and lower bounded values of the k th negotiation for the upper-level and lower-level programming problems, respectively. Additionally, $W_u(k+1)$ and $V_\ell(k+1)$ are the upper and lower bounded values of the $(k+1)$th negotiation, respectively.

4. Case study

4.1. The Taipei Port Container Logistic BOT Project

This case study uses financial data for the Container Terminal in the Taipei Port BOT Project to demonstrate the applicability of the proposed models.

The Taipei Port, located in Taipei County, will be the second largest international seaport in Taiwan after Kaohsiung Harbor once all seven container piers, run by the BOT project, are operational in 2014. The annual container handling capacity is predicted to by MOTC to reach 1.75 million 20-foot equivalent units (TEUs) by 2000. Under the BOT project, a concessionaire consisting of three private sector firms, the Evergreen Marine Corp, Yangming Marine Transport Corp, and Wan Hai Lines, Ltd., will jointly invest NT$20.32 billion (US$584 million) into this project to construct this seven-pier container port during the concession period.

Some important issues, including the concession period, scope of operations and operational content, financial stipulations, and royalties, must be determined through negotiations between the two parties and then the Concession Contract for the Container Terminal in Taipei Port must be completed. Based on background data of the Taipei Port BOT project, this section uses this case study to simulate the negotiation process using the operational output-based royalty, the operating revenue-based royalty, and lump-sum royalty models (Section 3.2).

According to the Terms of Reference (TOR) of Concessions of the Container Terminal in Taipei Port issued by the Keelung Harbor Bureau in 2000, some key aspects of this project are as follows.

(a) The scope of this BOT project covers the seven wharves in the container terminal.
(b) The duration of the concession period is 50 years. The construction period is 2001–2010. According to the TOR of this BOT project, the concessionaire constructed seven wharves; wharves 6 and 7 (W6 and W7) were completed at the end of 2004 and were operating at the start of 2005; W8–W9 and the container yard were scheduled to be completed by the end of 2007. The other wharves, W10–W12, were completed by the end of 2010 and started operations in 2011.
(c) We assume the annual volume of containers handled at W6 and W7 during 2005–2006 is 500,000 TEUs. By 2008, the assumed annual container volume handled at four wharves was 1,000,000 TEUs. During 2011–2050 (2050 is the end of the concession period), the seven wharves will handle 1,750,000 TEUs.
(d) The basic corporate income tax rate is 25%; however, according to the AFPPIPs, the concessionaire has a corporate income tax exemption for up to 5 years. Therefore, we assume the tax exemption period is 2005–2009.
(e) We assume the interest rate on government bonds is 8%. We also assume the inflation rate is 3.5%.

Table 1
Summary of TOR of the Container Terminal in the Taipei Port BOT Project. *Sources*: Terms of Reference (TOR) of "Concessions of Container Terminal in Taipei Port".

Item	Summary
Concession period	Years
Implementation schedule	Contract negotiation phase: 2001, construction period: 2001–2007, operating period: 2005–2050
No. of wharves	7
Total project installation cost (including government-related costs)	$US584 million (2001 currency)
Project phase and scales	a. 2005–2006, for two wharves: 0.5 million TEU/year b. 2007, for two wharves: 0.8 million TEU/year c. 2008, for four wharves: 1.0 million TEU/year d. 2011–2050, for seven wharves: 1.75 million TEU/year
Concession scope	a. Seven wharves and storage yard with exclusive operation rights and land superficies b. Operation scope: vessel berthing, container loading/unloading, transshipping, transportation, warehouse and storage, and container repair business
Interest rate of government bonds	8%
Corporate income tax exemption	Maximum of 5 years, exemption period 2005–2009 corporate income tax rate is 25%
Subsidy	No subsidy

The construction period is 2001–2004 ($n = 3$), and the operating period is 2005–2050; royalty collection begins in 2011 (Table 1). According to the TOR, the private sector investment rate of the total investment is 94%, and the government investment rate of the total investment is 6%. Conversely, we assume government investment items, such as the construction of access roads, land acquisition, and basic utility infrastructure, account for 10% of total project cost, which is approximately NT$653 million, $L = 653$; where L is the sum of the present value of the portion of construction costs the government agrees to pay. Moreover, we assume the discount rate is 10%, *i.e.*, $d = 10\%$, and annual cash flow is summed at the end of each year.

For the concession rate, when Cross (1965) proposed the concession rate concept, he assumed the concession rate of players I and II are given when applying the bargaining model. Following the work of Cross (1965) and Lin and Chang (2005), the concession rate of the government and private sector is assumed constant. Hence, the initial concession rate of the government and private firm would be 20% and 17%, respectively. Furthermore, we assume the time value discount rate and the learning rate are the same for both parties. That is, $a = b = 0.2$ and $\mu = v = 0.1$ (Cross, 1965; Lin and Chang, 2005).

4.2. Model application results

Financial data for this BOT project were substituted into the BLP problem of models I–III; and the proposed algorithm was implemented by each model. Both LINGO and MATLAB programming were used; both of which used the heuristic algorithm to simulate the bargaining process in royalty negotiation for both parties.

The initial solution of the upper-level programming problem is $\theta_u(k=0)$=0.032, and that of the lower-level programming problem is $\theta_\ell(k=0)$=0.006. That $\theta_u(k=0)$=0.032 indicates that the government first wants to receive a royalty of 0.032% of operating revenue during operation the period from the concessionaire according to the project TOR. However, $\theta_\ell(k=0)$=0.006 indicates that the private firm pays only 0.006% of operating revenue to the government. The convergence test does not hold. This demonstrates that the royalty was not determined by the two parties during the first negotiation because the private firm will not pay the royalty rate the government expected. As concession rate, time value discount rates, and learning rates affect decision variables of the two parties during the next negotiation, the assumed concession rates of $r_u(k=0) = 20\%$ and $r_\ell(k=0) = 17\%$, time value discount rates of $a = 0.2$ and $b = 0.2$, and learning rates of $\mu = 0.1$ and $v = 0.1$ were substituted into Eqs. (39)–(44) to modify the concession rate the next negotiation by the two parties. Steps 0–5 in the algorithm were then repeated. Table 2 shows simulation results of the royalty negotiation.

The solutions are $\theta_u(k=5) = 0.012$ and $\theta_\ell(k=5) = 0.012$ for the upper-level programming problem and lower-level programming problem, respectively (Table 2). As shown, the convergence test solution for the BLP problem held, indicating that the royalty negotiation by the two parties finished at the 5th negotiation. The solutions are $\theta_u(k) = 0.012$ and $\theta_\ell(k) = 0.012$ for the upper-level programming problem and lower-level programming problem, respectively. Thus, $\theta(k=5) = 0.012$ for the

Table 2
Simulation result of the royalty negotiation for the operating revenue-based model.

No. of negotiations	$r_u(k)$	$r_\ell(k)$	$\theta_u(k)$	$\theta_\ell(k)$	$\Pi_{G,R}(k)$	$\Pi_{P,R}(k)$
$k = 0$	0.200	0.170	0.032	0.006	13.252	1.082
$k = 1$	0.185	0.161	0.025	0.007	12.790	1.078
$k = 2$	0.172	0.152	0.021	0.008	12.447	1.075
$k = 3$	0.160	0.143	0.017	0.009	12.187	1.071
$k = 4$	0.148	0.135	0.014	0.011	11.988	1.067
$k = 5$	0.138	0.127	0.012	0.012	11.832	1.062

BLP problem. Consequently, simulation results indicate that the government can charge the concessionaire a royalty of 0.012% of operating revenue. Furthermore, the objective function values $\Pi_{G,R}(k=5)=11.832$ and $\Pi_{P,R}(k=5)=1.062$ for upper-level (government) and concessionaire (low-level) were also determined, respectively. This demonstrates that the government can obtain a finance recovery ratio of 11.832 times its investment cost and the concessionaire has an operational benefit of 1.062 based on the royalty negotiation result. Further, the decrease in concession rates for the two parties contributed to successful royalty negotiations; that is, royalty negotiation will cease when either party fails to change its concession rate. Moreover, simulation results of royalty negotiation indicate that the proposed royalty negotiation model, the operating revenue-based model, associated with above-mentioned factors, including concession rates, time value discount rates, and learning rates, can be applied to explain the negotiation behavior of both parties.

Similarly, by using the BLP heuristic algorithm, one can simulate the royalty negotiation for the operational output-based model and lump-sum royalty model. However, Eq. (38a) was replaced with Eq. (38b) when solving the BLP problem in the operational output-based royalty model, and Eq. (38a) was replaced with Eq. (38c) when solving the BLP problem in the lump-sum royalty model. Tables 3 and 4 show simulation results of royalty negotiation for the operational output-based royalty and the lump-sum royalty models, respectively.

For the operational output-based royalty model, the initial solution of the upper-level programming problem is $g_u(k=0)=0.0001$, while that of the lower-level programming problem is $g_\ell(k=0)=0.0019\%$. The $g_u(k=0)=0.0001$ value indicates that the government wants a royalty of 0.01% of operating output from the concessionaire during the operation period according to the project TOR. However, $g_\ell(k=0)=0.0019\%$ shows that the private firm pays only 0.0019% of operating quantity to the government. The convergence test did not hold because $\left|\frac{0.01\%*f_g-0.0019\%*f_p}{0.0019\%*f_p}\right|>0.01$ and $\left|\frac{0.01\%*f_g-0.0019\%*f_p}{0.01\%*f_g}\right|>0.01$.

The solutions are $g_u(k=5)=0.0000386$ and $g_\ell(k=5)=0.0000386$ for the upper- level programming problem and lower-level programming problem for the operational output-based model, respectively (Table 3). The convergence test solution for the BLP problem held. Therefore, the royalty negotiation for the two parties finished at the 5th negotiation. These simulation results imply that the government and private firm agree on a compromise royalty solution. Consequently, the government can charge the concessionaire a royalty of 0.00386% of operating output of this BOT project. At the same time, the objective function values $\Pi_{G,Q}(k=5)=11.6567$ and $\Pi_{P,Q}(k=5)=1.0675$ for the upper-level (government) and lower-level (concessionaire) were determined, respectively. These royalty negotiation results show that the government can obtain a government finance recovery ratio of 11.6567 times its investment and the concessionaire has an operational benefit of 1.0675 based on the royalty negotiation process for this BOT project. Additionally, the concession rates of $r_u(k=5)=0.1380$ and $r_\ell(k=5)=0.1270$ for the government and private firm were also obtained, respectively.

The solutions $F_u(k)=40.94$ and $F_\ell(k)=40.59$ for the upper-level programming problem and lower-level programming problem for model III were obtained, respectively (Table 4). The solution meets the convergence condition in Eq. (38c) of the algorithm, even though some minor differences exist between $F_u(k)=40.94$ and $F_\ell(k)=40.59$. Model findings indicate that the government can charge the concessionaire the lump-sum royalty of NT$40.94 million. Additionally, the objective functions for the upper-level and lower-level programming problems, $\Pi_{G,F}(k)=11.6890$ and $\Pi_{P,F}(k)=1.0621$, were found for this model, indicating that the government can obtain a government finance recovery ratio of 11.6890 times its investment and the concessionaire has an operational benefit of 1.0621 based on the lump-sum royalty method for this BOT project.

4.3. Analysis of alternative royalty strategies

To compare alternative royalty models, this study uses the objective functions, the government finance recover ratio, and profit index of BLP models to assess alternative royalty models the government and concessionaire can use based on Eqs. (1) and (2). Moreover, since we assumed these three models are independent in Section 2, the objective functions of the BLP problems can be ranked by government finance recovery ratio and profit index. The objective function values for the BLP problem are obtained as $\Pi_{G,Q}(k=5)=11.6567$ and $\Pi_{P,Q}(k=5)=1.0675$, $\Pi_{G,R}(k=5)=11.832$ and $\Pi_{P,R}(k=5)=1.062$, and $\Pi_{G,F}(k=5)=11.6890$ and $\Pi_{P,F}(k=5)=1.0621$ for models I–III, respectively (Tables 2–4). From the government's perspective, variation in the government finance recovery ratio is $\Pi_{G,R}(k=5)=11.832>\Pi_{G,F}(k=5)=11.6890>\Pi_{G,Q}(k=5)=11.6567$. However, changes in the profit index of the concessionaire are $\Pi_{P,Q}(k=5)=1.0675>\Pi_{P,F}(k=5)=1.0621>\Pi_{P,R}(k=5)=1.062$. $1.0675>\Pi_{P,F}(k=5)=1.0621>\Pi_{P,R}(k=5)=1.062$. These findings demonstrate that the operating revenue-based royalty

Table 3
Simulation result for royalty negotiation for the operational output-based model.

No. of negotiations	$r_u(k)$	$r_\ell(k)$	$g_u(k)$	$g_\ell(k)$	$\Pi_{G,Q}(k)$	$\Pi_{P,Q}(k)$
$k=0$	0.2000	0.1700	0.001	0.000019	12.7976	1.0843
$k=1$	0.1853	0.1608	0.00008	0.0000222	12.4258	1.0815
$k=2$	0.1719	0.1520	0.0000652	0.0000258	12.1503	1.0784
$k=3$	0.1596	0.1432	0.000054	0.0000297	11.9420	1.0750
$k=4$	0.1484	0.1350	0.0000454	0.000340	11.7878	1.0714
$k=5$	0.1380	0.1270	0.0000386	0.0000386	11.6567	1.0675

Table 4
Simulation result of royalty negotiation for the lump-sum royalty model.

No. of negotiations	$r_u(k)$	$r_\ell(k)$	$F_u(k)$	$F_\ell(k)$	$\Pi_{G,F}(k)$	$\Pi_{P,F}(k)$
$k = 0$	0.2000	0.1700	106	20	12.8813	1.0816
$k = 1$	0.1853	0.1608	84	23.4	12.4928	1.0784
$k = 2$	0.1719	0.1520	69.08	27.16	12.2048	1.0748
$k = 3$	0.1596	0.1432	57.20	31.28	11.9871	1.0709
$k = 4$	0.1484	0.1350	48.07	35.77	11.8198	1.0667
$k = 5$	0.1380	0.1270	40.94	40.59	11.6890	1.0621

Table 5
Sensitivity analysis result for the operating revenue-based royalty model.

Items	k	$\theta_u(k)$	$\theta_\ell(k)$	$\Pi_{G,R}(k)$	$\Pi_{P,R}(k)$
$r_u(k) = 0.2$, $r_\ell(k) = 0.04$	8	0.00941	0.00924	11.6261	1.0721
$r_u(k) = 0.2$, $r_\ell(k) = 0.07$	7	0.01000	0.00988	11.6770	1.0695
$r_u(k) = 0.2$, $r_\ell(k) = 0.11$	6	0.01100	0.01080	11.7441	1.0664
$r_u(k) = 0.2$, $r_\ell(k) = 0.17$	5	0.01220	0.01210	11.8324	1.0621
$r_u(k) = 0.2$, $r_\ell(k) = 0.25$	4	0.01400	0.01370	11.9583	1.0581
$r_u(k) = 0.2$, $r_\ell(k) = 0.42$	3	0.01620	0.01590	12.1268	1.0506

Note: $r_u(k)$ is fixed and $r_\ell(k)$ changes.

model is preferable for the government and should be adopted by the host government. However, the operational output-based royalty model is preferable for the concessionaire and should be adopted by the public sector.

Furthermore, changes in concession rates of the two parties affect the number of negotiation sessions (Tables 2–4). At the same time, the concession rates of the two parties impact their objective functions. Clearly, $\Pi_{G,Q}(k)$ decreases from 12.7976 to 11.6567 when the number of negotiations increases. Similarly, $\Pi_{P,Q}(k)$ decreases from 1.0843 to 1.0675 as k increases for model I. For model II, $\Pi_{G,R}(k)$ also decreases from 13.252 to 11.832 and $\Pi_{P,R}(k)$ decreases from 1.082 to 1.062 as k increases. Moreover, $\Pi_{G,F}(k)$ decreases from 12.8813 to 11.6890 and $\Pi_{P,F}(k)$ decreases from 1.6890 to 1.0621 as k increases for model III.

4.4. Sensitivity analysis

Change in the concession rate of the two parties will change the decision variables of BLP problems and affect changes in the objective functions of these models (Tables 2–4). Hence, sensitivity analysis is applied to $r_u(k)$, $r_\ell(k)$, $\theta_u(k)$, $\theta_\ell(k)$, $\Pi_{G,R}(k)$, and $\Pi_{P,R}(k)$. Two cases are considered—$r_u(k)$ is fixed but $r_\ell(k)$ changes, and $r_u(k)$ changes but $r_\ell(k)$ is fixed. Tables 5 and 6 show sensitivity analysis results.

First, a sensitivity analysis while assuming $r_u(k)$ is fixed while $r_\ell(k)$ varies (Table 5) indicates that when $r_\ell(k)$ changes and $r_u(k)$ remains constant, $\Pi_{P,R}(k)$ decreases from 1.0721 to 1.0506, and $r_\ell(k)$ increases from 0.04 to 0.42 as $\Pi_{G,R}(k)$ increases from 11.6261 to 12.1268. At the same time, the number of negotiations decreased from 8 to 3 as $r_\ell(k)$ increased. In this case, as the concession rate decreased, and the amount of royalty the private sector must pay increased.

Similarly, this work applies sensitivity analysis when $r_\ell(k)$ is fixed and $r_u(k)$ changes. Table 6 shows analytical results, the number of negotiations k increases when $r_u(k)$ decreases, while the number of negotiations k decreases when $r_u(k)$ increases (Table 6). At the same time, $\Pi_{G,R}(k)$ decreases as $r_u(k)$ increases rapidly; however, $\Pi_{P,R}(k)$ increases as $r_u(k)$ increases. Analytical results (Table 4) indicate that $\Pi_{P,R}(k)$ will increase from 1.0435 to 1.0702 when $r_u(k)$ increases from 0.04 to 0.36; however, $\Pi_{G,R}(k)$ decreases from 12.2857 to 11.6423.

Sensitivity analysis clearly indicates that any change in the concession rate for any party will affect the number of negotiations, decision variables, $\Pi_{G,R}(k)$, and $\Pi_{P,R}(k)$. In other words, if either party keeps a constant concession rate, a royalty negotiation will not be settled easily, and the royalty negotiation may cease. That is to say, the learn effect or time value discount factors of bargaining cost for either party do not impact the concession rates at the kth negotiation. Additionally, a negative relationship exists among $r_\ell(k)$, k, and $\Pi_{P,R}(k)$, but a positive relationship exists among $r_\ell(k)$, k, and $\Pi_{G,R}(k)$ (Tables 5 and 6). Thus, as the concession rate of the private sector decreases and the number of negotiations decreases, the royalty paid to the government increases. However, as the concession rate of the government decreases the concession rate of the private sector does not change, resulting in a reduction in the number of negotiations, and $\Pi_{G,R}(k)$ decreases.

4.5. Discussion

Findings from this case study show that the operating revenue-based royalty model is best suited to governments, and the operational output-based royalty model is best suited to concessionaires. Chiou and Lan (2006) focused only on constructing many royalty computation methods, and did not investigate royalty determination from a negotiation perspective. The contributions of this study differ from those of Chiou and Lan. (1) This study proposed three novel royalty strategies—the

Table 6
Sensitivity analysis result for the operating revenue-based royalty model.

Items	k	$\theta_u(k)$	$\theta_\ell(k)$	$\Pi_{G,R}(k)$	$\Pi_{P,R}(k)$
$r_u(k) = 0.04$, $r_\ell(k) = 0.17$	11	0.0183	0.01810	12.2857	1.0435
$r_u(k) = 0.09$, $r_\ell(k) = 0.17$	8	0.0160	0.01570	12.1038	1.0516
$r_u(k) = 0.12$, $r_\ell(k) = 0.17$	7	0.0146	0.01450	12.0030	1.0547
$r_u(k) = 0.2$, $r_\ell(k) = 0.17$	5	0.0122	0.01210	11.8324	1.0621
$r_u(k) = 0.26$, $r_\ell(k) = 0.17$	4	0.0111	0.01090	11.7541	1.0661
$r_u(k) = 0.36$, $r_\ell(k) = 0.17$	11	0.0183	0.01810	12.2857	1.0435

Note: $r_u(k)$ varies and $r_\ell(k)$ is fixed.

operating-revenue based model, operational output-based model, and lump-sum model—via BLP from negotiation perspectives. (2) This work developed the heuristic algorithm for BLP problems that considers bargaining cost factors such as concession rates, time value discount rates, and learning rates. (3) Chiou and Lan (2006) did not provide information about which royalty strategy is preferable for the private sector or government. Nevertheless, this study uses the royalty negotiation model to determine the royalties and compares alternative royalty strategies in the royalty negotiation models. Notably, the operating revenue-based royalty strategy is best suited to government, while the operational output-based royalty strategy is best suited to a concessionaire. However, Chiou and Lan did not address this issue.

As analyzed in Sections 4.2–4.4, study results demonstrate that model development for royalty determination by BLP can be applied to investigate or simulate the negotiation process for two parties. However, some issues warrant discussion.

(1) Many algorithms, such that a genetic algorithm (GA) and Tabu search, can be applied to solve BLP problems (Bard, 2002; Calvete et al., 2008). Previous algorithms can find the globally optimized solution to the BLP problem. However, in this study, the solution to the BLP problem using the "iterative algorithm" is a "compromise solution" for both parties. This differs from global optimization obtained by a GA or other optimization algorithms.
(2) In contrast to conventional negotiation and bargaining theories, concession rate, learning effect, and time value discount rate are factors in the bargaining process, which was addressed by Cross (1965). Shen et al. (2007) and Lin and Chang (2005) also adopted the work by Cross (1965) to investigate the concession period and revenue-sharing for a BOT project. Likewise, this work also used the concept and formulas developed by Cross (1965) and Lin and Chang (2005) to determine the royalty for a BOT project. Unlike the work by Shen et al. (2007), which used the Rubinstein model, and that by Lin and Chang (2005), which adopted the Cross model, this work adopts the BLP approach. However, the concession rates, time value discount rates, and learning effect are given, such that this BLP problem could be handled using negotiator learning, concession rate, and time value discount rate for each negotiation. Conversely, a negotiator's attitude toward risk and negotiation cost can also be incorporate into concession rate formulas.
(3) When analyzing negotiation behavior, many royalty negotiation models are based on the independent relationship assumption; this assumption warrants reexamination in further studies. In fact, for most BOT projects, a government can adopt royalty strategies combining two or more royalty computation methods; for example, a government can combine the fixed royalty fee and operational output-based model, the fixed royalty fee and variation royalty method, or fixed royalty and operating revenue-based royalty model to improve operation effectiveness during the operational period. Notably, the lump-sum royalty model is a simple strategy with an easy collection method for two parties.

5. Conclusions and suggestions

This work constructs three novel royalty negotiation models, namely the lump-sum royalty, operational revenue-based royalty, and operational output-based royalty, using the BLP approach from a negotiation perspective, and develops a novel heuristic algorithm to solve the BLP problem for governments and the private sector. This study also uses the case study of the Taipei Port Container Logistic BOT Project to determine the amounts of royalty derived using the three royalty methods. The two parties acquire the best concession negotiation result at the fifth negotiation with all three royalty models. Additionally, analytical findings indicate that the priority profit index of a concessionaire for the three models is $\Pi_{P,Q}(k = 5) = 1.0675 > \Pi_{P,F}(k = 5) = 1.0621 > \Pi_{P,R}(k = 5) = 1.062$, and the priority of the government finance recovery rate for the three models is $\Pi_{G,R}(k = 5) = 11.832 > \Pi_{G,F}(k = 5) = 11.6890 > \Pi_{G,Q}(k = 5) = 11.6567$. The operational revenue-based royalty model suits best governments, while the operational output-based royalty model favors most concessionaires. Moreover, the findings of the sensitivity analysis indicate that these factors have significant effects on the bargaining process.

The main contribution of the paper is that it proposes a new appealing research topic for BOT projects or PPP, because previous studies have neglected the impact of changes in royalty on financial viability of BOT projects, focusing mainly on three specific research issues including risks, relationship, and financing in PPP or BOT area. We have attempted to develop alternative royalty negotiation models and analyze strategies from the negotiation perspective. Factors, which had not been taken into account in previous research on bargaining model, including the concession rate, learning rate, and time value discount rate for both parties, are incorporated into the developed heuristic algorithm. We hope that the analytical model and framework for royalty determination and royalty strategy analysis utilized here can be applied to other BOT cases and can be further extended to analyze multi-party royalty schemes and strategies.

The case study in this research shows that the proposed royalty negotiation models can be utilized to explain negotiation behavior. In particular, the simulation results indicate that changes in concession rate of two parties affect significantly the number of negotiation sessions; and that the objective functions also change with the concession rates. In other words, the impact of factors of bargaining cost including concession rate, learning rate, and time value discount rate of two parties on the bargaining process should be considered. Nevertheless, survey data for time value discount, concession rate, and learning rate of two parties in each negotiation are needed when utilizing royalty negotiation models to investigate royalty determination in real BOT projects.

The following issues can be explored in future studies. (1) Some assumptions of the operational output-based royalty model can be released. Although concession rate, learning rate, and time value discount rate of two parties for solving the BLP problem are given to simplify analysis, these factors can be reexamined in future studies. Researchers can survey data for these factors via a questionnaire. (2) Other studies can utilize this analytical framework to investigate other royalty strategies, such as a mixed royalty method combining two or more royalty strategies. In addition, multiple issues in the bargaining model and multi-level programming problem can be addressed in future research to explore multi-party negotiation issues for BOT projects. (3) The Rubinstein bargaining model can be employed to analyze different royalty strategies for two parties.

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Further reading

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