Optimal Concession Contracts for Landlord Port Authorities to Maximize Fee Revenues

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Abstract

This paper analyzes optimal concession contracts offered by a landlord port authority to competing operators of container terminals. The port authority pursues fee-revenue maximization. Three contract schemes considered are fixed-fee, unit-fee, and two-part tariff. A two-stage game is constructed to characterize interactions between the port authority and two terminal operators. We discover that when marginal service costs of the less-efficient operator are small, the port authority would choose between the two-part tariff and the unit-fee schemes. Oppositely, the two-part tariff and the unit-fee schemes are equally preferred. Finally, if both terminal operators' efficiency is identical, the two-part tariff contract is the best.

Keywords : Concession contract, fixed-fee, unit-fee, landlord port, sequential game, two-part tariff

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1. Introduction

During past few decades, port authorities have transformed to meet the need of rapidly growing international trades and competitive environments. One obvious change is that these authorities in some countries shift from owners and operators to landlords of ports, as documented in Slack and Fremont (2005). Landlord authorities lease lands and superstructures of ports to private sectors by signing concession contracts. These contracts itemize how terminal operators pay for the rented capital facilities and lands of ports. Whether this change brings benefits for ports would depend on the designs of corresponding concession contracts. Since game theory is helpful in characterizing interactions among economic agents, we try to explore port authorities' optimal concession contracts in a game theoretical framework.

We construct a sequential game here. In this model, a port authority first announces the contract she offers, then two terminal operators compete in service prices or cargo amounts. The port authority seeks to maximize fee revenues collected from terminal operators through the signed contracts. The types of contract considered are fixed-fee, unit-fee, and two-part tariff. We find that when the less-efficient operator's marginal service costs are small, either the two-part tariff or unit-fee scheme would be favored. Oppositely, the two-part tariff and unit-fee schemes would have the same fee revenues at equilibria, and be equally preferred. Finally, if both terminal operators' efficiency is identical, the two-part tariff contract would be selected. We also investigate how optimal concession contracts are affected by model's parameters, such as operators' marginal service costs and their service differentiation degree. The results of this study will provide port authorities useful information in designing concession contracts.

We are not the first to investigate concession contracts. The relationships between our work and relevant literature are as follows. Trujillo and Nombela (2000) provide a formal definition that concession contracts ought to specify payments, obligations, and risk allocations between port authorities and terminal operators. For simplicity, we focus only on the payment part of concession contracts. De Monie (2005) identifies three-type general concession contracts based on ports' traffic volumes. Our unit-fee and fixed-fee schemes are special cases of De Monie's (2005). Jansson and Ryden (1979), Button (1979), and Strandenes and Marlow (2000) all suggest that port authorities use two-part tariff schemes to charge shipping liners. Nevertheless, Ferrari and Basta (2009) show that two-part tariff contracts are not efficient, thus propose a better fee scheme adjustable to the consumer price index. Different from the four papers above, interactions between the port authority and terminal operators and competitive behaviors of the operators are analyzed in our setup. On the other hand, surveys of Notteboom and Verhoeven (2010) reveal that the most often included clauses in the contracts between port authorities and terminal operators in Europe relate to the throughput guarantee. Marques and Fonseca (2010) propose several performance indicators to measure and to improve ports' regulating processes in Portugal. In contrast, this study concentrates on the fee-revenue maximization property of concession contracts for landlord port authorities. Cruz and Marques (2012) explore risk-sharing of several Portuguese concession contract, while we focus on payment parts of concession contracts.

Saeed and Larson (2010) adopt a Bertrand game framework to explore how terminal operators' pricing and port authority's profits in Pakistan vary with different types of concession contracts. Their simulation outcomes exhibit that optimal concession contracts offered by the port authority should have high unit fee and low annual rent. However, the *other* operator's contracts are hold fixed when Saeed and Larson (2010) examine how different contracts offered to *one* terminal operator affect port authority's profits. This setting may not be consistent with real-world situations because terminal operators often bid for contracts simultaneously. Our study makes no such assumption. And we obtain the analytical or closed-form solutions for optimal concession contracts for port authorities, instead of using simulation. On the other hand, Fu and Zhang

(2010) analyze the concession revenues shared by airports and airlines. They find that the sharing design brings higher social welfare, but may cause more serious competition among airliners. Fu and Zhang (2010) focus on two-part tariff contracts, while we compare three-type concession contracts for the port authority.

The contract types inspected in this study have been widely adopted in the literature on patent holders' licensing behaviors. Our setup differs from models of licensing literature in two respects. First, firms' marginal costs would decrease after patent licenses being purchased in their models, while terminal operators' costs stay the same in our setup after contracts being signed. Therefore, our optimal concession contracts depend on terminal operators' marginal service costs, rather than innovation sizes in the licensing literature. Second, many earlier works of licensing (e.g., Kamien and Tauman, 1986; Kamien et al., 1992) compare merely fixed-fee and unit-fee contracts, but we compare three contract types as in the later licensing literature (e.g., Giebe and Wolfstetter, 2008; Poddar and Sinha, 2010; Meniere and Parlane, 2010). Moreover, we discover two-part tariff contracts are not necessarily superior to the other two for port authorities, as found in the later licensing literature. Nevertheless, the existence conditions of our equilibrium contracts are different from those in licensing literature.

The rest of this paper is organized as follow. The model is presented in Section 2. Terminal operators' optimal behaviors are derived and described in Section 3. Optimal concession contracts are demonstrated in Section 4. Properties of the optimal contracts are explored in Section 5. Finally, conclusions and policy implications are drawn in Section 6. Additionally, all proofs are in the Appendix.

2. The Model

Our model has one port authority and two container terminal operators. The terminal operators provide shipping liners differential services, which may result from different amounts of cranes and gantries uploading and unloading containers, distinct locations of terminals, or dissimilar storage facilities for cargos. Accordingly, the inverse market demand functions faced by operators 1 and 2 are assumed to be respectively

$$p_1 = 1 - q_1 - bq_2 \text{ and} \tag{1}$$

$$p_2 = 1 - q_2 - bq_1, \tag{2}$$

where p_i is the price of unit cargo (e.g., Twenty Foot Equivalent Units, TEU) charged by operator i, and q_i is the amount of cargo handled by operator i, $i = 1, 2$. Parameter $b \in (0, 1)$ represents the service substitution degree of the operators. The larger b is, the higher the service substitution degree is. Providing services to shipping liners incurs costs. The total cost of managing terminals consists of a fixed and a variable parts. The fixed cost refers to expenditures spent on equipments, such as cranes and gantries. Denote K_i and γ_i the equipment level and the unit (rental) price of equipment for operator i. Then, $\gamma_i K_i$ is operator i's fixed cost. In contrast, let $c_i q_i$ be operator i's variable cost, which changes with cargo numbers handled at rate c_i with $1 > c_i > 0$ for $i = 1, 2$. The variable cost includes labor costs uploading and unloading cargos, storage fees of cargos, etc. In sum, operator i's total cost

$$C_i(q_i) = c_i q_i + r_i K_i, \ i = 1, 2. \tag{3}$$

Without loss of generality, we assume that $c_2 \geq c_1$. This means that operator 1 is at least as efficient as operator 2. Since $r_i K_i$ is independent of operator i's service prices and cargo amounts, neglecting $r_i K_i$ in (3) will not alter our results qualitatively. Thus, for simplicity, (3) can be reduced to

$$C_i(q_i) = c_i q_i. \tag{4}$$

In our model, the port authority can offer terminal operators three types of concession contracts. The first charges terminal operators a fixed fee, $f > 0$, which is independent of the cargo amount handled. The second charges operators a unit fee, r, for per unit cargo uploading or unloading. The third is a two-part tariff scheme, (r, f), which combines the previous two. That is, the port authority collects both fixed and unit fees from the operators. Here, for simplicity, we ignore overcharge in the congested period. Accordingly, the authority's revenues under the fixed-fee, unit-fee, and two-part tariff schemes are $2f$, $r(q_1+q_2)$, and $2f+r(q_1+q_2)$, respectively. Our landlord port authority could be a local government or an international port management company, pursuing fee-revenue maximization.[1]

On the other hand, terminal operators are assumed to maximize their profits, which vary with contract types offered. Given two-part tariff scheme $(r,\ f)$, profits of operators 1 and 2 are

$$\pi_1 = p_1q_1-(c_1+r)q_1-f=[1-q_1-bq_2]q_1-(c_1+r)q_1-f \text{ and} \tag{5}$$

$$\pi_2 = p_2q_2-(c_2+r)q_2-f=[1-q_2-bq_1]q_2-(c_2+r)q_2-f \tag{6}$$

by (1), (2) and (4). Under the unit-fee scheme, operators' profit functions are (5)-(6) with $f=0$. Under the fixed-fee scheme, operators' profit functions are (5)-(6) with $r=0$. Like traditional firm theory, terminal operators could compete in cargo amounts (the Cournot mode) or service prices (the Bertrand mode). Since the two modes lead to similar qualitative results, we present quantity competition results only. And the price competition outcomes are available upon request.

Our sequential game proceeds as follows. First, the port authority announces a fee scheme to maximize her revenues. Second, given the fee scheme, terminal operators 1 and 2 simultaneously and independently choose their optimal cargo amounts to maximize profits. Because this is a complete information game, the subgame perfect Nash equilibrium (hereafter SPNE) can be obtained through backward induction. We first derive terminal operators' equilibrium cargo amounts and service prices in Section 3, given a concession contract. Then, optimal concession contracts for the port authority

[1]When the port authority only has fee income, and her cost (e.g., the expenditure of constructing and managing infrastructures of ports) is independent of the fee type, maximizing fee revenues is equivalent to maximizing profits.

are acquired in Section 4.

3. Optimal Behaviors of Terminal Operators

Given each of the three fee schemes, the associated optimal behaviors of terminal operators are derived in the following subsections.

3.1. Under Two-Part Tariff Scheme

Given two-part tariff $(r,\ f)$, operators 1 and 2 choose optimal cargo amounts $(q_1^*,\ q_2^*)$ to solve the following problems.

$$\begin{aligned}\max_{q_1\geq 0}\ \pi_1 &= [1-q_1-bq_2]q_1-(c_1+r)q_1-f \text{ and}\\ \max_{q_2\geq 0}\ \pi_2 &= [1-q_2-bq_1]q_2-(c_2+r)q_2-f.\end{aligned}$$

The associated Kuhn-Tuker conditions for $(q_1^*,\ q_2^*)$ are

$$\frac{\partial \pi_1}{\partial q_1} = 1-2q_1-bq_2-(c_1+r)\leq 0,\ q_1\cdot\frac{\partial \pi_1}{\partial q_1}=0,\ \text{and} \tag{7}$$
$$\frac{\partial \pi_2}{\partial q_2} = 1-2q_2-bq_1-(c_2+r)\leq 0,\ q_2\cdot\frac{\partial \pi_2}{\partial q_2}=0. \tag{8}$$

By solving the equality parts of (7)-(8), i.e, $\frac{\partial \pi_i}{\partial q_i}=0$ for $i=1,\ 2$, we obtain[2]

$$q_1^* = \frac{1-r}{2+b}+\frac{[bc_2-2c_1]}{4-b^2} \text{ and} \tag{9}$$
$$q_2^* = \frac{1-r}{2+b}+\frac{[bc_1-2c_2]}{4-b^2}. \tag{10}$$

When equilibrium cargo amounts are positive, the second-order and stability conditions hold because $\frac{\partial^2\pi_i}{\partial q_i^2}=-2<0$ and $\frac{\partial^2\pi_i}{\partial q_i^2}\cdot\frac{\partial^2\pi_j}{\partial q_j^2}-\frac{\partial^2\pi_i}{\partial q_j\partial q_i}\cdot\frac{\partial^2\pi_j}{\partial q_i\partial q_j}=(4-b^2)>0$ for $i,\ j=$

[2]Under some concession contracts, two operators, especially operator 2, may not rent the terminals. Accordingly, we need to consider both interior ($q_i^*>0$) and boundary ($q_i^*=0$) solutions. These solutions can be derived from (9)-(10). For instance, $q_2^*>0$ if $r<\frac{2(1-c_2)-b(1-c_1)}{2-b}$, while $q_2^*=0$ if $r=\frac{2(1-c_2)-b(1-c_1)}{2-b}$. Thus, we focus on (9)-(10). More details can be found in (13) and footnote 3.

1, 2. Substituting (9)-(10) into (1)-(2) yields equilibrium prices charged by terminal operators 1 and 2,

$$p_1^* = \frac{1+r(1+b)}{2+b} + \frac{[c_1(2-b^2)+c_2 b]}{4-b^2} > 0 \text{ and} \tag{11}$$

$$p_2^* = \frac{1+r(1+b)}{2+b} + \frac{[c_2(2-b^2)+c_1 b]}{4-b^2} > 0. \tag{12}$$

To have nonnegative equilibrium cargo amounts for both operators, the following conditions are assumed.[3]

$$c_2 < \bar{c}_2 \equiv 1 - \frac{b(1-c_1)}{2} \text{ and } r \le \bar{r} \equiv \frac{2(1-c_2)-b(1-c_1)}{2-b}. \tag{13}$$

Inequalities in (13) say that operator 2's marginal service cost (c_2) and port authority's unit fee (r) cannot be too large so that both operators will handle nonnegative cargo amounts. In particular, if $r = \bar{r} > 0$, we have $q_2^* = 0$. That is because operator 2 will exit the market if the authority charges unit fee too high. By (9)-(12), terminal operator i's profit is

$$\pi_i^* \equiv (q_i^*)^2 - f,\ i = 1,\ 2. \tag{14}$$

3.2. Under Unit-Fee Scheme

Given unit fee r, operators 1 and 2 choose optimal cargo amounts $(q_1^u,\ q_2^u)$ to solve the following problems.

$$\max_{q_1 \ge 0} \pi_1 = [1 - q_1 - bq_2]q_1 - (c_1 + r)q_1$$
$$\max_{q_2 \ge 0} \pi_2 = [1 - q_2 - bq_1]q_2 - (c_2 + r)q_2.$$

The associated first-order conditions are the same as (7)-(8). Accordingly, equilibrium cargo amounts $(q_1^u,\ q_2^u)$ and equilibrium prices $(p_1^u,\ p_2^u)$ satisfy

$$q_i^u = q_i^* \text{ and } p_i^u = p_i^*,\ i = 1,\ 2. \tag{15}$$

[3] The condition of $r \le \frac{2(1-c_1)-b(1-c_2)}{2-b}$ implies $q_1^* \ge 0$, while the condition of $r \le \frac{2(1-c_2)-b(1-c_1)}{2-b}$ suggests $q_2^* \ge 0$. Since $c_2 \ge c_1$, the later condition implies the former.

Similarly, to have nonnegative q_i^u, conditions in (13) are imposed. However, operator i's profit at equilibrium is

$$\pi_i^u \equiv (q_i^u)^2, \ i = 1, \ 2. \tag{16}$$

3.3. Under Fixed-Fee Scheme

Given fixed fee f, operators 1 and 2 choose optimal cargo amounts $(q_1^f, \ q_2^f)$ to solve the following problems.

$$\begin{aligned}\max_{q_1 \geq 0} \pi_1 &= [1 - q_1 - bq_2]q_1 - c_1 q_1 - f \\ \max_{q_2 \geq 0} \pi_2 &= [1 - q_2 - bq_1]q_2 - c_2 q_2 - f.\end{aligned}$$

The associated first-order conditions are the same as (7)-(8) with $r = 0$. Thus, we have

$$q_1^f = \frac{1}{2+b} + \frac{[bc_2 - 2c_1]}{4-b^2} \text{ and} \tag{17}$$

$$q_2^f = \frac{1}{2+b} + \frac{[bc_1 - 2c_2]}{4-b^2}. \tag{18}$$

It is worthy to mention that $q_i^f > 0, \ i = 1, \ 2,$ under the first condition in (13). The equilibrium prices charged by operators 1 and 2 are respectively

$$\begin{aligned}p_1^f &= \frac{1}{2+b} + \frac{[c_1(2-b^2) + c_2 b]}{4-b^2} > 0 \text{ and} \\ p_2^f &= \frac{1}{2+b} + \frac{[c_2(2-b^2) + c_1 b]}{4-b^2} > 0.\end{aligned}$$

Accordingly, terminal operator i's equilibrium profit equals

$$\pi_i^f \equiv (q_i^f)^2 - f, \ i = 1, \ 2. \tag{19}$$

4. Optimal Concession Contracts

In the following subsections, we will derive port authority's optimal fee choices and compare her equilibrium revenues in different schemes. Then optimal fee scheme(s) with maximum revenues can be uncovered.

4.1. Optimal Two-Part Tariff Scheme

Given $(q_1^*,\ q_2^*,\ \pi_1^*,\ \pi_2^*)$ in (9), (10) and (14), the port authority will choose $(r^*,\ f^*)$ to solve the problem of

$$\begin{aligned} &\max_{r,\,f}\ 2f + r(q_1^* + q_2^*) \\ \text{s.t.}\quad &0 \le r \le \bar{r},\ \pi_1^* \ge 0,\ \pi_2^* \ge 0,\ f \le \min\{\pi_1^*,\ \pi_2^*\}. \end{aligned} \tag{20}$$

Constraint $0 \le r \le \bar{r}$ from (13) is to guarantee both operators handling nonnegative cargo amounts. Condition $\pi_i^* \ge 0$ is so-called the individual rationality constraint for operator i, under which the operator is willing to rent terminals from the authority to earn nonnegative profits. Without loss of generality, each operator's minimum required profit is assumed to be zero. Our results will not change qualitatively if operators' minimum required profits become positive. They are available upon request. Finally, since π_i^* is the maximum amount operator i is willing to pay, the fixed fee set by the port authority should not exceed operators' willingness to pay. That is why the condition of $f \le \min\{\pi_1^*,\ \pi_2^*\}$ is imposed. By solving (20), we obtain the followings.

Lemma 1. *Suppose that conditions in (13) hold. Given operators' optimal cargo amounts* $(q_1^*,\ q_2^*)$ *and equilibrium profits* $(\pi_1^*,\ \pi_2^*)$, *the optimal two-part tariff scheme* $(r^*,\ f^*)$ *is given below.*

(i) *If* $c_2 \le \hat{c}_2$, *we have* $r^* = \frac{1}{(4b+6)}\{(2+2b) + \frac{c_2 b^2}{(2-b)} - \frac{(4+2b-b^2)c_1}{(2-b)}\} > 0,\ f^* = \frac{1}{2}(q_2^*)^2 > 0,$ *and* $q_i^* > 0$ *for* $i = 1,\ 2$, *where* $\hat{c}_2 = \frac{1}{b+6}[(4-2b) + c_1(3b+2)]$ *with* $c_1 < \hat{c}_2 < \bar{c}_2$. *Accordingly, equilibrium fee revenue under the scheme equals*

$$R^* = 2f^* + r^*(q_1^* + q_2^*) \equiv 2f^* + r^*\left[\frac{(2-2r^*)}{(2+b)} - \frac{(2-b)(c_1+c_2)}{(4-b^2)}\right]. \tag{21}$$

(ii) *If* $\hat{c}_2 < c_2 < \bar{c}_2$, *we have* $r^* = \bar{r} = \frac{2(1-c_2)-b(1-c_1)}{2-b}$, $f^* = 0$, *and* $q_2^* = 0$. *Accordingly, equilibrium fee revenue under the scheme equals*

$$R^* = \bar{r}q_1^* = \frac{(c_2-c_1)[2(1-c_2)-b(1-c_1)]}{(2-b)^2}. \tag{22}$$

Lemma 1 shows that operators' marginal service costs and their service differentiation degree are important in deciding port authority's optimal two-part tariff contracts. When operator 2's marginal cost is small (i.e., $c_2 \leq \hat{c}_2$), both operators will rent terminals from the port authority. However, since operator 2 is less efficient than operator 1, it will handle fewer cargos and earn fewer profits than operator 1. Thus, operator 2 is willing to pay smaller fixed fee than operator 1. And the port authority will use operator 2's willingness to pay as her optimal fixed fee. Moreover, optimal unit fee will be less than its upper bound ($\bar{r}$) due to small c_2. That is what Lemma 1(i) shows.

In contrast, if operator 2's marginal service cost is large (i.e., $c_2 > \hat{c}_2$), the operator will have little gain and rent no terminal from the port authority. Thus, operator 2 handles zero cargo and earns zero profit. Because the minimum of operators' willingness to pay for fixed fee is zero, the port authority charges zero fixed fee. To maximize revenues, the port authority will charge operator 1 as large unit fee as possible. That is what Lemma 1(ii) demonstrates.

4.2. Optimal Unit-Fee Scheme

Given $(q_1^u,\ q_2^u,\ \pi_1^u,\ \pi_2^u)$ in (15) and (16), the port authority will choose unit fee r^u to solve the problem of

$$\begin{aligned}&\max_{r}\ r(q_1^u + q_2^u)\\&\text{s.t. } 0 \leq r \leq \bar{r},\ \pi_1^u \geq 0,\ \pi_2^u \geq 0.\end{aligned} \tag{23}$$

The constraints in (23) are the same as those in (20) except that the upper bound for fixed fee is deleted. By solving (23), we obtain the followings.

Lemma 2. *Given terminal operators' optimal cargo amounts* $(q_1^u,\ q_2^u)$ *and equilibrium profits* $(\pi_1^u,\ \pi_2^u)$, *port authority's optimal unit fee* r^u *is determined below.*
(i) *If* $c_2 \leq \hat{c}_2 = \frac{4-2b+c_1(2+3b)}{b+6}$, *then* $r^u = \frac{1}{2} - \frac{(c_1+c_2)}{4} \geq 0$ *and* $q_i^u > 0$ *for* $i = 1,\ 2.$

Accordingly, port authority's equilibrium fee revenue under the scheme is

$$R^u = r^u(q_1^u + q_2^u) = \frac{1}{2(2+b)}[1 - \frac{(c_1+c_2)}{2}]^2. \tag{24}$$

(ii) *If* $\hat{c}_2 < c_2 < \bar{c}_2$, *then* $r^u = \bar{r} = \frac{2(1-c_2)-b(1-c_1)}{2-b}$, $q_2^u = 0$, *and port authority's equilibrium fee revenue under the scheme is*

$$R^u = \bar{r}q_1^u = \frac{(c_2-c_1)[2(1-c_2)-b(1-c_1)]}{(2-b)^2} = R^* \text{ in (22)}. \tag{25}$$

As in Lemma 1, Lemma 2 displays that port authority's optimal unit fee depends on both operators' marginal service costs and their service differentiation degree. Since the intuition behind Lemma 2 is similar to that of Lemma 1, it is omitted here. In particular, both (22) and (25) suggest that for large c_2, the port authority has the same equilibrium fee revenues under the two-part tariff and unit-fee schemes. That is because the authority will set zero fixed fee in the two-part tariff scheme and charge the same unit fee in the two schemes.

4.3. Optimal Fixed-Fee Scheme

Given $(q_1^f,\ q_2^f)$ in (17)-(18) and $(\pi_1^f,\ \pi_2^f)$ in (19), the port authority will choose f^f to solve the problem of

$$\begin{aligned} &\max_f \ 2f \\ \text{s.t.}\ &\pi_1^f \geq 0,\ \pi_2^f \geq 0,\ f \leq \min\{\pi_1^f,\ \pi_2^f\}. \end{aligned} \tag{26}$$

The constraints in (26) are the same as those in (20) except that the upper bound for unit fee is deleted. By solving (26), we obtain the followings.

Lemma 3. *Given terminal operators' optimal cargo amounts* $(q_1^f,\ q_2^f)$ *and equilibrium profits* $(\pi_1^f,\ \pi_2^f)$, *we have* $f^f = \frac{1}{2}(q_2^f)^2$ *and* $q_i^f > 0$ *for* $i = 1,\ 2$. *Accordingly, equilibrium fee revenue under the scheme equals*

$$R^f = (q_2^f)^2 = [\frac{1}{(2+b)} + \frac{(bc_1 - 2c_2)}{(4-b^2)}]^2. \tag{27}$$

Since operator 1 is at least as efficient as operator 2, it will handle more or equal cargo amounts and earn higher or equal profits compared to operator 2. This suggests that operator 2's willingness to pay for the fixed fee is no greater than operator 1's. Thus, the port authority will use operator 2's willingness to pay as the optimal fixed fee. Furthermore, since both operators have positive profits at equilibria, they will rent terminals from the port authority. That is the content of Lemma 3.

Finally, by comparing R^*, R^u and R^f, we obtain port authority's optimal concession contracts as follows.

Proposition 1. (i) *Suppose* $c_2 \leq \hat{c}_2 = \frac{4-2b+c_1(2+3b)}{b+6}$. *Then we have* $R^f \leq R^u$, $R^f \leq R^*$ *and* $R^* \geq (\leq) R^u$ *iff* $G \geq (\leq) 0$, *where* G *is defined in (30). That is, either the two-part tariff or the unit-fee scheme is preferred.*
(ii) *Suppose* $\hat{c}_2 < c_2 < \bar{c}_2$. *Then we have* $R^u = R^*$ *and* $R^* \geq R^f$. *Thus, the two-part tariff and the unit-fee schemes are equally favored.*

Proposition 1 demonstrates that the port authority will select either the two-part tariff or the unit-fee scheme, depending on terminal operators' marginal service costs and their service differentiation level. When operator 2's marginal service costs are small, the two-part tariff or the unit-fee scheme would be preferred. When operator 2's marginal costs are large, the two-part tariff and unit-fee schemes would generate the same revenues at equilibria and are equally favored. These outcomes are explained below.

First, we compare the fixed-fee and unit-fee schemes under small c_2. Equations (24) and (27) imply

$$R^u - R^f = r^u(q_1^u + q_2^u) - (q_2^f)^2.$$

We can show $r^u \geq q_2^f$ and $(q_1^u + q_2^u) \geq q_2^f$. This means that port authority's optimal unit fee is large, and both operators handle more cargos under the unit-fee scheme than operator 2 does under the fixed-fee scheme. Thus, the unit-fee contract will bring higher revenues to the port authority, suggesting that the unit-fee is better than the fixed-fee scheme. Next, by (21) and (27),

$$R^* - R^f = (q_2^*)^2 + r^*(q_1^* + q_2^*) - (q_2^f)^2.$$

Since $q_2^f \geq q_2^*$ by (10) and (18) for all unit-fee values (r), we have $(q_2^f)^2 \geq (q_2^*)^2$. This implies that fixed-fee revenues collected from the fixed-fee scheme are no fewer than those from the two-part tariff scheme. However, revenues from the two-part tariff scheme contain the unit-fee and fixed-fee parts, and the former outweighs the latter. That is because more efficient operator 1 handles a larger amount of cargos under the two-part tariff scheme and pays a larger amount of unit fees, but revenues under the fixed-fee scheme are unaffected by operator 1's equilibrium cargo amount.[4] This implies that the two-part tariff scheme is preferred to the fixed-fee scheme.

Then, it remains to compare the two-part tariff and unit-fee schemes. By (21) and (24),

$$R^* - R^u = (q_2^*)^2 + r^*(q_1^* + q_2^*) - r^u(q_1^u + q_2^u).$$

We can obtain $r^* \leq r^u$ and $(q_1^* + q_2^*) \geq (q_1^u + q_2^u)$ by $c_2 \leq \hat{c}_2$.[5] This implies that the port authority will charge lower unit fee under the two-part tariff scheme than under the unit-fee scheme. But both terminal operators will handle more cargos under the two-part tariff scheme. To judge relative sizes of unit-fee revenues under the two schemes, we need to know the sign of $[r^*(q_1^* + q_2^*) - r^u(q_1^u + q_2^u)]$. By some calculations, we have

$$r^*(q_1^* + q_2^*) - r^u(q_1^u + q_2^u) = \frac{(r^u - r^*)}{2+b}[2(r^u + r^*) - 2 + c_1 + c_2] \leq 0$$

because $2(r^u + r^*) - 2 + c_1 + c_2 = \frac{-1}{2b+3} + \frac{c_2(6+b)}{2(2-b)(2b+3)} - \frac{(3b+2)c_1}{2(2-b)(2b+3)} \leq 0$ by $c_2 \leq \hat{c}_2$. This suggests that the port authority will collect smaller unit-fee revenues under the two-part tariff scheme. Nevertheless, if fixed-fee revenues under the two-part tariff scheme

[4]We can show $R^* - R^f = r^*[q_1^* + \frac{b}{2+b}q_2^* - \frac{q_2^f}{2+b}] \geq 0$ because $q_1^* + \frac{b}{2+b}q_2^* - \frac{q_2^f}{2+b} = \frac{(4b+6)r^*}{2(2+b)^2} > 0$. Since $q_2^* \leq q_2^f$, the outcome of $R^* \geq R^f$ must be due to large enough q_1^*.

[5]That is because $r^* \geq (\leq)\ r^u$ iff $c_2 \geq (\leq)\ \hat{c}_2$, and $(q_1^* + q_2^*) - (q_1^u + q_2^u) = \frac{2(r^u - r^*)}{2+b} \geq (\leq)\ 0$ iff $c_2 \leq (\geq)\ \hat{c}_2$.

are large enough, this scheme will still be preferred. Otherwise, the unit-fee scheme will be chosen. That is what Proposition 1(i) states.

Two numerical examples are provided here to demonstrate Proposition 1(i) further. Suppose b is close to 1 and $c_1 = 0.1$. Then we have $\hat{c}_2 = 0.357$. By taking $c_2 = 0.2 < \hat{c}_2$, we can obtain $G \approx 0.010116 > 0$. This implies $R^* > R^u$. In contrast, if b is close to zero and $c_1 = 0.1$. We have $\hat{c}_2 = 0.7$. By taking $c_2 = 0.7$, we can obtain $G \approx -0.000373 < 0$. This suggests $R^* < R^u$. In the first example, large b leads to small $\hat{c}_2$, hence a small range for c_2. Since operator 2's marginal service costs are small, it can handle large amounts of cargos. Accordingly, fixed-fee incomes would outweigh unit-fee incomes under the two-part tariff scheme. And the two-part tariff contract is preferred. In contrast, in the second example, small b causes large $\hat{c}_2$. Because operator 2's marginal service costs can be large, it will handle fewer cargos. Then the port authority cannot collect large fixed-fee revenues under the two-part tariff scheme. Accordingly, the unit-fee contract is favored.

When c_2 is large, the port authority will use the unit-fee upper bound ($\bar{r}$) as optimal unit fee under both the two-part tariff and unit-fee schemes, and set zero fixed fee in the two-part tariff scheme as shown by Lemma 1(ii) and Lemma 2(ii). Thus, the authority will have the same revenues under the two-part tariff and unit-fee schemes. Then, it remains to compare the fixed-fee and two-part tariff schemes. By (22) and (27),

$$R^* - R^f = \bar{r}q_1^* - (q_2^f)^2.$$

We can illustrate $\bar{r} \geq q_2^f$ and $q_1^* \geq q_2^f$ by $\hat{c}_2 < c_2 < \bar{c}_2$. This means that the unit fee under the two-part tariff scheme is large, and operator 1 would handle more cargos under the two-part tariff than operator 2 would under the fixed-fee scheme. That is because operator 2's high marginal service costs result in fewer cargos handled. Accordingly, we have $R^* \geq R^f$, hence the two-part tariff and the unit-fee schemes are equally favored. That is the content of Proposition 1(ii).

Finally, we discuss a special and interesting case of Proposition 1, i.e., two terminal operators having symmetric costs, $c_1 = c_2 = c$. Then Lemma 1(ii) and Lemma 2(ii) would not occur, because $\hat{c}_2 > c_1$ is shown in Lemma 1(i) and to have $c_1 < \hat{c}_2 < c_2$ and $c_1 = c_2$ hold together is impossible. By simple calculations, we can acquire $R^* = \frac{(1-c)^2}{2b+3}$, $R^u = \frac{(1-c)^2}{2(2+b)}$, and $R^f = \frac{(1-c)^2}{(2+b)^2}$. Therefore, $R^* > R^u > R^f$ and the outcome is summarized below.

Corollary 1. *Suppose* $c_1 = c_2 = c$. *Then the two-part tariff scheme will be the best concession contract for the port authority.*

When terminal operator 2 becomes as efficient as operator 1, its equilibrium cargo amounts and profits would increase. Then the port authority can earn more fixed-fee incomes under the two-part tariff scheme, and the two-part tariff contract becomes superior to others.

5. Properties of Optimal Concession Contracts

As shown in Proposition 1, the port authority would favor the two-part tariff or the unit-fee contract. It is worthy to know how the two contracts are affected by model's parameters, such as operators' marginal service costs and their service differentiation degree. First, we present the properties of optimal two-part tariff and unit-fee schemes under small c_2.

Lemma 4. (i) *Suppose* $c_2 \leq \hat{c}_2$. *Given optimal two-part tariff contract* $(r^*,\ f^*)$ *derived in Lemma 1(i), we have the followings.*
(ia) $\frac{\partial r^*}{\partial c_1} = \frac{-(4+2b-b^2)}{(4b+6)(2-b)} < 0$ *and* $\frac{\partial f^*}{\partial c_1} = q_2^*[\frac{-1}{2+b} \cdot \frac{\partial r^*}{\partial c_1} + \frac{b}{4-b^2}] > 0.$
(ib) $\frac{\partial r^*}{\partial c_2} = \frac{b^2}{(4b+6)(2-b)} > 0$ *and* $\frac{\partial f^*}{\partial c_2} = q_2^*[\frac{-1}{2+b} \cdot \frac{\partial r^*}{\partial c_2} - \frac{2}{4-b^2}] < 0.$
(ic) $\frac{\partial r^*}{\partial b} = \frac{4(4-4b+b^2)-8c_1(2+b)+2bc_2(b+12)}{(4b+6)^2(2-b)^2} \geq \frac{6b^2}{(4b+6)^2(2-b)^2} > 0$ *and* $\frac{\partial f^*}{\partial b} = q_2^*[\frac{-(2b+12)}{(4b+6)(2+b)^2} + \frac{c_1(3b^3+18b^2+44b+48)+c_2(-2b^3-44b^2-73b+2)}{(4b+6)(2+b)^2(2-b)^2}] < 0.$
(ii) *Suppose* $\hat{c}_2 < c_2 \leq \bar{c}_2$. *Given optimal unit-fee contract* r^u *derived in Lemma 2(i),*

we have $\frac{\partial r^u}{\partial c_1} = \frac{\partial r^u}{\partial c_2} = -1/4 < 0$ *and* $\frac{\partial r^u}{\partial b} = 0$.

Under two-part tariff scheme $(r^*,\ f^*)$, when operator 1's marginal service costs (c_1) rise, it will handle fewer cargos but operator 2 will handle more because their services are strategic substitutes. The former will lead to lower unit-fee incomes, while the latter will bring higher fixed-fee incomes for the port authority. Since $\frac{\partial q_1^*}{\partial r} = \frac{-1}{2+b} < 0$ implied by (9), the port authority can lower the unit fee to offset the effect of operator 1's handling fewer cargos. That is what Lemma 4(ia) states. In contrast, if operator 2's marginal costs (c_2) rise, it will handle fewer cargos but operator 1 will handle more. The former will lead to lower fixed-fee revenues, while the latter will bring higher unit-fee revenues for the port authority. To compensate the loss on the fixed-fee part, the port authority would raise the unit fee. That is displayed in Lemma 4(ib). When the service differentiation degree (b) between the two operators increases, the market becomes more competitive. Thus, operator 2 will handle fewer cargos due to less efficiency. Accordingly, port authority's fixed-fee revenues will decrease. To compensate this loss, the authority will raise the unit fee. That is claimed by Lemma 4(ic).

Next, when the unit-fee scheme is chosen and operator i's marginal service costs rise, the operator will handle fewer cargos. The port authority can only lower the unit fee to counter the cargo-amount decreasing. Moreover, the optimal unit fee is independent of operators' service differentiation level. That is what Lemma 4(ii) demonstrates.

Finally, for large c_2, we have the followings.

Lemma 5. (i) *Suppose* $\hat{c}_2 < c_2 < \bar{c}_2$. *Given optimal two-part tariff or unit fee* $(\bar{r},\ f^* = 0)$ *derived from Lemma 1(ii) or Lemma 2(ii), we have* $\frac{\partial \bar{r}}{\partial c_1} = \frac{b}{2-b} > 0$, $\frac{\partial \bar{r}}{\partial c_2} = \frac{-2}{2-b} < 0$, $\frac{\partial \bar{r}}{\partial b} = \frac{2b(1-c_2)+(1-c_1)(-2+b-b^2)}{(2-b)^2} < 0$.

Recall that $\bar{r}$ is the maximum unit fee the port authority can charge, and is derived from the constraint of non-negative equilibrium cargo amounts of operator 2. Thus, if operator 1's marginal costs increase, operator 2 will handle more cargos and the upper bound for the unit fee will rise. In contrast, if operator 2's marginal costs increase, it will handle fewer cargos and the upper bound for the unit fee will fall. Finally, when the service substitution degree between the two operators increases, operator 2 will handle fewer cargos due to tighter competition. Thus, the upper bound for the unit fee will fall.

6. Conclusions and Policy Implications

This paper investigates optimal concession contracts for a landlord port authority trying to maximize her fee revenues. A two-stage game proceeds as follows. The port authority first decides a contract, then two terminal operators choose their cargo amounts or service prices independently and simultaneously. The contracts considered include fixed-fee, unit-fee, and two-part tariff schemes. We find that based on terminal operators' marginal service costs and their service differentiation levels, the port authority will choose between the two-part tariff and the unit-fee contracts. In particular, if two operators' marginal service costs are the same, the authority would prefer the two-part tariff scheme. Moreover, we explore how optimal concession contracts are affected by operators' marginal service costs and their service differentiation degree. Once data of these variables are available, port authority's optimal concession contracts can be identified.

There are two possible extensions for this paper. First, uncertainty can be added to our setup. In the real world, shocks from the demand and cost sides often exist. Thus, it is worthy to explore how uncertainty affects port authorities' optimal concession contracts and terminal operators' pricing behaviors. Second, risk sharing among agents is a significant issue especially when they face uncertainty. Therefore, this issue together with uncertainty can be examined in the future.

Appendix

Proof of Lemma 1: (i) For a given $(r,\ f)$, we have $q_1^* - q_2^* = \frac{(2+b)(c_2-c_1)}{4-b^2} \geq 0$ by (9)-(10). This implies $q_1^* \geq q_2^*$ and $\pi_1^* \geq \pi_2^*$. Thus, $f^* = \min\{\pi_1^*,\ \pi_2^*\} = \pi_2^* = (q_2^*)^2 - f^*$, suggesting $f^* = \frac{1}{2}(q_2^*)^2$. Accordingly, $\pi_1^* = (q_1^*)^2 - \frac{1}{2}(q_2^*)^2 \geq 0$ and $\pi_2^* = \frac{1}{2}(q_2^*)^2 \geq 0$. Then, problem of (20) can be reduced to

$$\max_r\ (q_2^*)^2 + r(q_1^* + q_2^*)$$
$$\text{s.t.}\ \ 0 \leq r \leq \bar{r}.$$

Define Lagrangian function $L = (q_2^*)^2 + r(q_1^* + q_2^*) - \lambda[r - \bar{r}]$. The associated Kuhn-Tucker conditions are

$$\frac{\partial L}{\partial r} = 2q_2^*\frac{\partial q_2^*}{\partial r} + r(\frac{\partial q_1^*}{\partial r} + \frac{\partial q_2^*}{\partial r}) + q_1^* + q_2^* - \lambda \leq 0,\ r \cdot \frac{\partial L}{\partial r} = 0, \tag{28}$$
$$\frac{\partial L}{\partial \lambda} = \bar{r} - r \geq 0,\ \lambda\frac{\partial L}{\partial \lambda} = 0. \tag{29}$$

There are two possible solutions as follows.

Case 1: Suppose $\lambda = 0$. Then we can find $r^* > 0$ meeting the condition of $\frac{\partial L}{\partial r} = \frac{1}{(2+b)^2}[(2+2b) - r(4b+6) - \frac{c_1(4+2b-b^2)}{(2-b)} + \frac{c_2 b^2}{(2-b)}] = 0$ by (28). The second-order condition holds because $\frac{\partial^2 L}{\partial r^2} = \frac{-(4b+6)}{(2+b)^2} < 0$. Thus, $r^* = \frac{1}{(4b+6)}\{(2+2b) - \frac{(4+2b-b^2)c_1}{(2-b)} + \frac{c_2 b^2}{(2-b)}\} > 0$. It remains to check whether $r^* \leq \bar{r}$. By some calculations, we have

$$r^* - \bar{r} = \frac{1}{(2-b)(4b+6)}[2b^2 - 8 - c_1(3b^2 + 8b + 4) + c_2(b^2 + 8b + 12)].$$

Thus, $r^* \leq \bar{r}$ if $c_2 \leq \hat{c}_2 \equiv \frac{1}{(b+6)}[c_1(3b+2) + 2(2-b)]$ with $c_1 < \hat{c}_2 < \bar{c}_2$. That is because $\bar{c}_2 - \hat{c}_2 = \frac{(4-b^2)(1-c_1)}{2(6+b)} > 0$ and $\hat{c}_2 - c_1 = \frac{(4-2b)(1-c_1)}{6+b} > 0$. Under the circumstance, $q_1^* = \frac{1-r^*}{2+b} + \frac{bc_2-2c_1}{4-b^2} > 0$, $q_2^* = \frac{1-r^*}{2+b} + \frac{bc_1-2c_2}{4-b^2} > 0$, $f^* = \frac{1}{2}(q_2^*)^2 > 0$, and $R^* = (q_2^*)^2 + r^*(q_1^* + q_2^*)$.

Case 2: Suppose $\lambda > 0$. Then we have $r^* = \bar{r}$ by (29), which occurs when $c_2 > \hat{c}_2$. Under the circumstance, we have $q_1^* = \frac{(2+b)(c_2-c_1)}{4-b^2}$, $q_2^* = 0$, $f^* = 0$, and $R^* = \bar{r}q_1^* = \frac{(c_2-c_1)[2(1-c_2)-b(1-c_1)]}{(2-b)^2}$. □

Proof of Lemma 2: When $q_i^u \geq 0$, implied by $r \leq \bar{r}$, we have $\pi_i^u \geq 0$ for $i = 1,\ 2$. Thus, problem (23) can be reduced to

$$\max_r \ r(q_1^u + q_2^u)$$
$$\text{s.t. } 0 \le r \le \bar{r}.$$

Denote $L = r(q_1^u + q_2^u) - \lambda[r - \bar{r}]$ the Lagrange function. Then the associated Kuhn-Tucker conditions are

$$\begin{aligned}\frac{\partial L}{\partial r} &= r(\frac{\partial q_1^u}{\partial r} + \frac{\partial q_2^u}{\partial r}) + q_1^u + q_2^u - \lambda \le 0,\ r \cdot \frac{\partial L}{\partial r} = 0, \\ \frac{\partial L}{\partial \lambda} &= \bar{r} - r \ge 0,\ \lambda \frac{\partial L}{\partial \lambda} = 0.\end{aligned}$$

By similar arguments adopted by Lemma 1, we can obtain $r^u = \frac{1}{2} - \frac{(c_1+c_2)}{4} > 0$ if $c_2 \le \hat{c}_2$. Therefore, $q_1^u = \frac{1}{(2+b)}[\frac{2+c_1+c_2}{4} + \frac{bc_2-2c_1}{(2-b)}] > 0$, $q_2^u = \frac{1}{(2+b)}[\frac{2+c_1+c_2}{4} + \frac{bc_1-2c_2}{(2-b)}] > 0$, and $R^u = \frac{1}{2(2+b)}[1 - \frac{(c_1+c_2)}{2}]^2$. For $c_2 > \hat{c}_2$, we have $r^u = \bar{r}$, $q_2^u = 0$, $R^u = \bar{r}q_1^u = \frac{(c_2-c_1)[2(1-c_2)-b(1-c_1)]}{(2-b)^2}$. □

Proof of Lemma 3: Since $q_i^f > 0$, we have $\pi_i^f = (q_i^f)^2 \ge 0$ by (19). By (17) and (18), we have $q_1^f - q_2^f = \frac{(2+b)(c_2-c_1)}{4-b^2} \ge 0$. Then, $q_1^f \ge q_2^f$ and $\pi_1^f \ge \pi_2^f$. Thus, $f = \min\{\pi_1^f,\ \pi_2^f\} = \pi_2^f = (q_2^f)^2 - f$, implying $f^f = \frac{1}{2}(q_2^f)^2$. Accordingly, $\pi_1^f = (q_1^f)^2 - \frac{1}{2}(q_2^f)^2 \ge 0$ and $\pi_2^f = \frac{1}{2}(q_2^f)^2 \ge 0$. At f^f, we have $R^f = (q_2^f)^2 = [\frac{1}{2+b} + \frac{bc_1-2c_2}{4-b^2}]^2$. □

Proof of Proposition 1: (i) By (24) and (27), we have

$$R^f - R^u = (q_2^f)^2 - r^u(q_1^u + q_2^u).$$

Since $(q_2^f - r^u) = \frac{1}{4(4-b^2)}[2b(b-2) + c_1(4+4b-b^2) - c_2(4+b^2)] \le \frac{2b(b-2)(1-c_1)}{4(4-b^2)} < 0$ and $q_2^f - (q_1^u + q_2^u) = \frac{(b+2)(c_1-c_2)}{2(4-b^2)} \le 0$ by $c_2 \ge c_1$, we have $R^f \le R^u$. Moreover, by (21), (27) and some calculations, we have

$$\begin{aligned}R^* - R^f &= (q_2^*)^2 + r^*(q_1^* + q_2^*) - (q_2^f)^2 \\ &= r^*[q_1^* + \frac{b}{2+b}q_2^* - \frac{r^*}{(2+b)^2}] = \frac{(2b+3)(r^*)^2}{(2+b)^2} \ge 0\end{aligned}$$

due to $q_2^f = q_2^* + \frac{r^*}{2+b}$. This suggests $R^f \le R^*$. On the other hand, by (21) and (24), we have

$$R^* - R^u = G \ge\ (\le)\ 0 \text{ iff } G \ge\ (\le)\ 0,$$

where

$$
\begin{aligned}
G &= \frac{2b^2+7b+6}{2(2+b)^2(2b+3)^2} - \frac{F^2}{4(2+b)^2(2b+3)} - \frac{c_2(b^2+4b+6)(bc_1-2c_2)}{(2+b)^2(2-b)^2(2b+3)} \\
&\quad + \frac{(c_1+c_2)}{2(2+b)(2b+3)}\{1+\frac{[c_2(-2b^2-b-6)+c_1(-2b^2+7b+10)]}{4(2-b)}\} \\
&\quad + \frac{(bc_1-2c_2)[2(4-b^2)+c_1(b+1)(b+4)]}{(2+b)^2(2-b)^2(2b+3)} \qquad (30)
\end{aligned}
$$

could be positive with $F = \frac{-c_2b^2}{2-b} + \frac{c_1(4+2b-b^2)}{2-b}$.

(ii) Since $R^u = R^*$ by (25), we need only compare R^* and R^f. By (22) and (27), we have

$$R^* = \bar{r}q_1^* \text{ and } R^f = (q_2^f)^2.$$

By simple calculations, we have

$$
\begin{aligned}
\bar{r} - q_2^f &= \frac{2(1-c_2)-b(1-c_1)}{2-b} - \frac{1}{2+b} - \frac{bc_1-2c_2}{4-b^2} = \frac{1+b}{2+b}[1+\frac{bc_1-2c_2}{2-b}] \\
&> \frac{1+b}{2+b}\{1+\frac{bc_1}{2-b} - \frac{2}{2-b}[-1+\frac{b(1-c_1)}{2}]\} \\
&= \frac{2(1+b)}{2+b}[1+\frac{bc_1}{2-b}] > 0
\end{aligned}
$$

by $c_2 < \bar{c}_2 = 1 - \frac{b(1-c_1)}{2}$, and

$$
\begin{aligned}
q_1^* - q_2^f &= \frac{(2+b)(c_2-c_1)}{4-b^2} - \frac{1}{2+b} - \frac{bc_1-2c_2}{4-b^2} = \frac{[c_2(4+b)-c_1(2+2b)]}{4-b^2} - \frac{1}{2+b} \\
&> \frac{4+b}{(4-b^2)} \cdot \frac{[4-2b+c_1(2+3b)]}{(6+b)} - \frac{(2+2b)c_1}{(4-b^2)} - \frac{1}{(2+b)} \\
&= \frac{(1-c_1)}{6+b} > 0
\end{aligned}
$$

by $c_2 > \hat{c}_2 = \frac{4-2b+c_1(2+3b)}{6+b}$. This then implies $R^* \geq R^f$. □

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